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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONRASIA, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest. This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large. It is available free of charge to approved members of the DOD scientific community. Send written request describing DOD affiliation to: Director, Office of Naval Research, Asian Office, Unit 45002, APO AP 96337-0007.

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Electronics Science

Cover: The southern view of the Australian National University (ANU) campus taken at dawn, from the air. Courtesy of Prof. Michael A. McRobbie, Executive Director of the Center for Information Science Research (CISR) at ANU. For a closer look at CISR and ANU, see David Kahaner's article on computing in Australia on page 47.

SIBRIEFS

Scientific Information Briefs

JAPANESE COMPANIES WILLING TO RECEIVE U.S. RESEARCHERS

The National Science Foundation (NSF) sponsors an active Japan program for U.S. scientists. As part of that program they have prepared a directory of approximately 150 Japanese companies that have said they are willing to receive American researchers at their laboratories. The list was compiled by mailing questionnaires to 553 companies with more than 30 researchers listed in the *All Japan Research Institutes Directory*. Of these, 284 companies responded and 154 provided positive responses. NSF's directory lists each company as well as specific information about its activities, personnel, facilities, and the type of research the company is interested in supporting. Names and addresses of contacts are also given for each. This directory, as well as other information, can be obtained from the NSF at:

Japan Programs
Division of International Programs
National Science Foundation
Washington, DC 20550

or by fax at (202) 357-5839.--*David K. Kahaner, ONRASIA*

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SYMPLECTIC INTEGRATION COMMENTS

Editor's Note: David Kahaner has been receiving interesting responses to his electronically distributed report on scientific activities in China (see page 17). A relevant one, by James C. Scovel (address below), deals with "symplectic integration" research by Feng Kang of the Chinese Academy of Sciences.

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Scovel's comments about the history of symplectic integration are as follows.

In 1983 both Ruth and Channell did different types of symplectic algorithms. Ruth's was published in an IEEE journal while Channell's was in a Los Alamos internal report. Feng Kang published on this subject in 1986 but did little implementation. He should be credited with being the first to set out a systematic course of study or approach. He and his collaborators were also the first to deal with the preservation of first integrals of the motion. Feng's student Ge Zhong, who is now in the United States, has done very excellent work of this sort.

Research on numerical methods for Hamiltonian systems is active, for example, see "Symplectic Integration of Hamiltonian Systems," *Nonlinearity* 3, 231-259 (1990), by Channell and Scovel. These sort of algorithms should be very important for satellite stability and control, underwater acoustics, and any Hamiltonian systems of interest. Please note that it is correct that they do very well in the long run, but even in the short run they usually do better since the bifurcation scenarios are different in the symplectic category than the general.

In addition to classical Hamiltonian systems there are Poisson Hamiltonian systems, which are Hamiltonian with respect to a Poisson bracket that do not come from a symplectic structure. Examples are the Euler equation for a rigid body, the Euler equation for incompressible fluids, the compressible fluid equations, the Vlasov-Poisson and Maxwell-Vlasov equation of plasma physics, and many more. For these the symplectic integrators are more complicated but can be done. See "Integrators for Lie-Poisson Dynamical Systems," *Physica* D 50, 80-88 (1991), by Channell and Scovel.

Now this last paper only addresses the finite dimensional problem and we are in the process of completing a large work titled "Numerical Integration of Finite Dimensional Lie-Poisson Approximations to Vlasov-Poisson Equations" by Channell, Scovel, and Weinstein. The numerical results are very good. In fact, this whole work should extend directly the fluid equations mentioned above. To be honest, it is only a matter of time before these techniques will be standard.--*James C. Scovel, Los Alamos National Laboratory*

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THE NEW MINISTRY OF INTERNATIONAL TRADE AND INDUSTRY (MITI) MICROMACHINE TECHNOLOGY PROGRAM

Introduction

In FY1991, MITI proposed a new 10-year project, Micromachine Technology, to establish the technologies necessary for the realization of micromachines for (1) medical devices of a few hundred micrometers diameter capable of diagnoses and treatments in human organs without injuring the human body, and (2) moving microrobots for inspections and repairs in complicated mechanical systems such as pipes in power plants or aircraft engines without disassembly or destruction of the total systems.

The Micromachine Technology project will be conducted by the New Energy and Industrial Technology Development Organization (NEDO) under the authority of the Agency of Industrial Science and Technology (AIST) like other research and development (R&D) projects. A schedule for this project has not yet formally been decided.

Micromachine Technology

Micromachines are microscopic machines or instruments with advanced functions that can perform minute tasks or work in extremely narrow spaces. Their microscopic size permits them to have a wide variety of applications, including in medicine, biotechnology, and industry.

Recently, the frontiers of this field have been rapidly opened up by silicon (Si) micromachining technology, in which micrometerorder mechanical structures are formed on Si wafers. This technology emerged out of etching, deposition, and other lithographic techniques for microprocessing silicon that were developed in the 1970s and enabled the production of cantilevers, diaphragms, and other simple mechanical components. These products are now used widely as pressure sensors or are beginning to be commercialized as acceleration sensors and flow sensors. Moreover, recent advances in semiconductor microprocessing and ultraprecision processing technology have allowed mechanical parts to be created far smaller than anything previously developed.

Research into micromachine technology, however, has only recently gotten underway and many technological barriers need to be overcome before such machines can be developed, including those related to friction, durability, strength, materials, and power sources and supplies. There are a number of other technologies that must also be developed, including ways to design, process, assemble, and control micromachines.

Since research into micromachines has only just begun, the purpose of this project is to develop basic technologies required to create micromachines for various applications that we are now able to envision.

Micromachines Today

There are currently two approaches to developing micromachines: (1) technology in the field of mechanical engineering that makes existing mechanisms even smaller and (2) micro electro mechanical systems (MEMS) technology, which makes use of integrated circuit (IC) production technology. Many researchers have proposed or built prototypes of various microactuators and microstructures that could serve as the component technologies for micromachines. Some examples of these are discussed below.

In the United States, schools like the University of California-Berkeley, the Massachusetts Institute of Technology (MIT), Stanford, the University of Wisconsin-Madison, and the University of Michigan are researching surface micromachining technology and LIGA (lithografie, galvanoformung, abformung) process technology in their silicon process research centers and LIGA process research centers.

Researchers at Berkeley have created a 120-mμm-diameter electrostatic motor and verified that it does rotate. They are also able to measure friction coefficients, one of the most difficult problems in micromachine technology, using a micro electrostatic linear actuator. At MIT, researchers have produced a 100-mμm-diameter polysilicon micromotor and analyzed its movement. The motor was created using the same process as for ICs. Rotation of 15,000 rpm was obtained. At Wisconsin-Madison, three-dimensional structures containing gears with an inside diameter of 55 mμm have been created.

The National Science Foundation (NSF) supports these efforts. In 1988, its micromachine research budget was distributed among 8 universities, and in 1989 funding was provided to 11 universities.

There are also several micromachining facilities in Europe, including Germany's Fraunhofer-Institut, Techische Universitat Berlin, Kernforschungszentrum Karlsruhe Institut fur Mikrostrukturetechnik, and the Netherlands University of Twente. Research concentrates mostly on sensors. The Fraunhofer Institut fur Mikrostrukturetechnik has produced prototypes of a vibration sensor with 32 cantilever-type mechanical resonators and a 1.5- by 1.25-mm cantilever-type thermal bimorph microactuator.

These facilities receive subsidies both from the European Community (EC) and from their respective countries.

In Japan, numerous creative studies related to micromachine technology have been made, e.g., prototypes of a micro Stirling engine with high thermal efficiency as a microactuator at the University of Tokyo; a microvalve using silicon at Tohoku University; and a 500- by 500-nm active integrated optical microencoder, which has a resolution of 0.01 mμm, at NTT Applied Electronics Laboratories.

In addition to the above, research at many universities, national research institutes, and private companies is producing prototypes of electrostatic linear actuators, micropressure sensors, micro ion-sensitive field effect transistor (ISFET) sensors, micromanipulators using piezoelectric-impact drive systems, microactive catheters using shape memory alloy (SMA), etc.

These technologies, which mainly use semiconductor production techniques, represent only a small part of micromachine production technology. Research in this field is still in its infancy, and many problems remain to be solved. Some of the hurdles to be overcome include developing production and process technologies that are geared specifically towards micromachines and solving questions related to friction, durability, strength, materials, power supplies, and control.

Application of the Results (Examples)

Micromachine technology will have a wide variety of applications. The main focus of this project will therefore be on common component technologies which, once developed, will probably result eventually in applications like the following.

Industrial Micromachines. Industry is faced with the need to boost reliability and reduce maintenance costs for increasingly advanced and complex mechanical systems and equipment (power plants and airplane engines are two good examples). There is a tremendous need for technology that makes it possible to perform inspections and repairs in extremely tight spaces without having to dismantle the entire system or equipment in question, such as plant pipe systems and airplane engines.

Industrial micromachines will enable inspection and repair without requiring that plant equipment be dismantled. This will make it possible to perform early inspection and repair to minimize the extent of damage. Significant improvements in capacity utilization and maintenance costs can therefore be expected for electric power plants and other facilities.

While this technology is under development, if robots can be developed that are able to remain inside various equipment or mechanical systems and monitor and repair them, maintenance work could be performed without having to shut down and dismantle complex machinery.

Medical Micromachines. The pain experienced during diagnosis and treatment is not sufficiently alleviated during today's medical procedures. As the population grows older there will be a strong demand for advanced medical equipment able to lessen the physical and mental stress inflicted on patients.

Micromachines will make it possible to create new medical equipment capable of performing diagnosis and treatment simply, accurately, and with less need for surgery. They will also contribute to the advancement of microsurgery techniques (eye surgery, suture of microscopic blood vessels, etc.) and the development of artificial organs to be placed inside the body.

In biotechnology, micromachines will be applied in cellular manipulation such as well separation, injections into cells, and cell fusion.

Description of This Research and Development

Though micromachines are small, they are complex systems with advanced functions. Some of the areas that need to be researched include: (1) the basic theories which underpin (a) miniaturization methods, (b) structural analysis, (c) materials, and (d) component technologies like microscopic processing and assembly; (2) techniques for producing microscopic sensors and control circuits; and (3) the system technology required to perform microscopic motion and operation. Given the above, it is necessary for industry, academia, and government to undertake R&D in cooperation. In as much as micromachine technology is a revolutionary new area that has attracted much interest around the world, some thought should be given to international cooperation in these research and development efforts.

The following are some of the main research and development topics envisioned for micromachine technology.

(1) Microscopic Mechanical Device Technology. R&D on structures, materials, machining techniques, integration techniques, and power supplies for microscopic mechanisms and functional components required for micromachines; development of technology to enable the production of various mechanical devices.

(2) Microscopic Sensors, Control Circuits, and Other Techniques for Miniaturized Electronic Devices. R&D in the technologies needed to produce extremely miniaturized electronic devices such as microscopic sensors and control circuits used in micromachines.

(3) Control and Operation Technologies. R&D in motion control and operation technologies for microscopic mechanisms.

(4) Measurement and Evaluation Technologies. Basic research into measurement methods, evaluation methods, and microscopic measurement technology as they relate to various component devices.

(5) Support Technologies. Basic research into support technologies for each of the above. Areas include lubrication techniques for microscopic parts, theoretical simulation, and computer-aided design/ manufacture (CAD/CAM).

(6) System Integration Technologies. In addition to making advances in component technologies, R&D on system integration technologies will be one of the main R&D topics.

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--David K. Kahaner, ONRASIA

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INTERNATIONAL CONGRESS ON ANALYTICAL SCIENCES 1991

One of the most broadly and widely used disciplines among the sciences is analytical chemistry. It plays a vital role in fields ranging from electronic material processing to chemical production to biosciences. The wide applicability of analytical chemistry was very much in evidence at the International Congress on Analytical Sciences 1991 (ICAS'91), which was sponsored by the International Union of Pure and Applied Chemistry (IUPAC) and organized by the Science Council of Japan and the Japan Society for Analytical Chemistry (JSAC). The conference chairperson, vice chairperson, and general secretary were, respectively, Professors Eiji Niki, Keiichiro Fuwa, and Yohichi Gohshi, all of Tokyo University. The term "Analytical Science" was used in the title instead of Analytical Chemistry to emphasize the broad nature of this discipline. This meeting was held on 25-31 August 1991, in part, in commemoration of the 40th anniversary of the founding of the JSAC. The venue was the new (and very large) Nippon Convention Center at Makuhari-Messe on the northern edge of Tokyo Bay about 25 miles east of Tokyo. This is one of many such centers that have recently been built in various locations in Japan.

There were approximately 1,100 attendees from 28 nations. Among these only about 20 were from the United States which, in my view, was a disappointingly small number. The meeting was divided into eight separate sessions plus two poster sessions. They were:

- Separation sciences
- Chemical speciation and characterization
- New principles, reactions, and techniques
- Chemometrics and robotics
- Biochemical/biomedical
- Environmental
- High tech materials
- Miscellaneous

In addition, the following special symposia were held:

- Asianalysis
- New frontiers of electroanalytical chemistry
- Laser analytical spectroscopy
- Bio- and chemiluminescence: application to analytical chemistry
- Recent advances in chromatography and electrophoresis
- Safety control and risk management
- Analytical sciences of high polymers

And finally, five special lectures were presented by invited speakers at two plenary sessions:

- Professor Richard R. Ernst, Eidgenössische Technische Hochschule, Zurich
- Professor Gabor A. Somorjai, University of California, Berkeley
- Professor Emeritus Keiichiro Fuwa, Tokyo University
- Dr. H. Rohrer, IBM, Zurich
- Dr. Lloyd A. Currie, National Institute of Standards and Technology, Gaithersburg, MD

I primarily attended the environmental sessions. Here the papers were about evenly divided among those concerned with water analysis and those for solid and gas samples. Several papers concerning organotin analysis were presented by the Japanese, which I found interesting because 10 years ago I could find almost no work going on in this area in Japan even though the field was very active in the United States and Europe. As with all meetings of this type, the most important aspect was that it provided an excellent opportunity for scientists to meet each other and discuss matters of mutual interest on a one-to-one basis.--*SachioYamamoto, ONRASIA*

* * * * *

SECOND NTT SCIENCE FORUM

Nippon Telegraph and Telephone Corporation (NTT) is the Ma Bell of Japan and is the major player in Japan's telecommunications industry. Until April 1985 it was a public (government) corporation solely responsible for the industry. However, like AT&T earlier, it was privatized in 1985 allowing competitors to enter the field. Nevertheless, it remains the largest of the companies that operate Japan's telecommunications network, the large size of which is evidenced by the fact that, with the exception of the United States, Japan has more telephones than any other nation in the world. As part of its effort to raise and enhance its image as a leader in science and technology, NTT in 1990 initiated a science forum program in which distinguished scientists in a particular field are invited to present lectures and discuss their work. The second of these forums was held on 10 April 1991 and its theme was "Marine Biotechnology - Ocean as a Source of Life." Two speakers from the United States, Professor Andrew A. Benson of the Scripps Institution of Oceanography and Professor Harlyn O. Halvorson of the Woods Hole Oceanographic Institution, were the invited lecturers. The formal lectures were followed by a panel discussion with Benson and Halvorson, who were joined by Professor Shigetoh Miyachi, executive managing director of the Marine Biotechnology Institute (MBI), and Professor Isao Karube of Tokyo University. The moderator was Mr. Akio Etori, the executive director and editor of Mita Press. Before the discussions began, Professors Miyachi and Karube gave brief presentations of their work.

Professors Benson and Halvorson each reviewed past work in the field of marine biotechnology and discussed contributions that can be expected. Benson reviewed the field in terms of marine products, health, and environment. Among the topics he discussed were the Manzanar Project to develop mariculture in the Red Sea, regulation of calcium by calcitonin from salmon, and the ability of some marine organisms to detoxify arsenic by synthesis of nontoxic arsenic compounds. The work at Woods Hole was the subject of Halvorson's presentation and included a discussion of novel resistance mechanisms to infectious diseases displayed by some marine organisms and the novel processes employed by certain marine bacteria (archebacteria) to withstand extreme environments.

Professor Miyachi described MBI, which was established last year in two locations, Shizuoka and Kamaishi. The institute is financed by government (Ministry of International Trade and Industry) and industry. Currently 24 companies provide funds and two-thirds of the researchers. Biodegradation of oil, bio-antifouling agents, and CO_2 extraction with marine algae are some of their projects. Professor Karube discussed studies related to the problem of global warming; among them were solar bioreactor experiments in Okinawa and CO_2 removal with coral.

Although the lectures presented "big picture" overviews rather than detailed discussions of specific research programs, the forum provided a good medium for people working in the field to get together.--*Sachio Yamamoto, ONRASIA*

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"NEW MATERIALS: FOUNTAINHEAD FOR NEW TECHNOLOGIES AND NEW SCIENCE"

The second of the International Science Lecture (ISL) Series was initiated in Tokyo on 15 October 1991 and featured Rustum Roy, Evan Pugh Professor of the Solid State and Professor of Geochemistry of Pennsylvania State University, who spoke on "New Materials: Fountainhead for New Technologies and New Science."

The ISL Series was established in 1990 by the National Academy of Sciences in response to a request from the Chief of Naval Research. The purpose of the series is to encourage the exchange of information among scientists in the United States and abroad, with the objective of establishing better lines of communication and improving our ability to assess the status of science efforts in other countries. At each site, a lecture by a distinguished U.S. scientist is followed by a roundtable discussion of problems of mutual interest. Each lecture is released as a report with excerpts from the roundtable discussions. Topics for lectures are chosen from areas of interest to the Office of Naval Research (ONR). The initial list of topics includes oceanography, materials research, and information science.

Professor Roy's lecture focused on ceramics research, an area where Japanese science is particularly strong. Roy's approach to science is "market oriented." The most promising opportunities lie in the *use* of science rather than the creation of new science. The demand for new technology can serve as the "glue" that brings together the extension of knowledge through basic research and development of new products in a concurrent process. Particular areas identified for future growth were (1) use of ceramics in optoelectronics, (2) thin films and fibers, and (3) "nanoscale" composite design concepts.

About 100 attendants came to hear the lecture. They consisted of leading materials scientists from Japanese industry and universities. The audience was strongly engaged by the lecture, which was followed by a lively discussion. There were also several U.S. scientists in the audience, and they appeared to help to catalyze the discussion. Active discussions continued in the post-lecture reception, and it was apparent that the lecture had been very stimulating to the audience. Japanese scientists appeared to want to identify technology areas that are of particular interest in the United States.

The lecture and reception were held in the U.S. Embassy in Tokyo. Ambassador Armacost personally gave a warm welcome to the audience. He described the International Science Lecture Series and the role of the National Academy of Sciences and the Office of Naval Research. The setting and the warm welcome helped to set the tone of openness and frankness for the event. Participation of the highest officials of the U.S. Embassy and the prestige of the U.S. National Academy of Sciences both greatly elevated the significance of the lecture for the Japanese participants. The style of the lecture was frank, open, and direct. Trends in the status of research and development efforts in ceramics in various countries were identified, and the lecturer pointed out the rapid growth of Japanese science in ceramics. The Japanese now play the leading role in the world in this area, and that fact was documented and freely acknowledged. All these factors contributed to unusually forthcoming participation by the Japanese scientists in the discussion.

The lecture and reception were followed by a roundtable discussion at a dinner meeting with a small number of very high level Japanese managers. The atmosphere of openness and free exchange of views continued. Clearly the lecture had been stimulating and had succeeded in creating the feeling that there would be an opportunity for accomplishing something. The participation of senior and greatly respected Japanese scientists also lent a feeling of importance to the dinner meeting. There was a strong consensus that the dinner discussion was successful and mutually beneficial and should therefore be continued through some appropriate mechanism. Followup activities were agreed on to be recommended for further consideration.

From this program we can conclude that there is a *major opportunity* for cooperation. The roundtable discussion has opened the door for further discussion and action with an influential and highly placed group of Japanese scientists and industrialists. With the right preparation and attention to key factors leading to successful exchanges, it is possible to have highly effective, open, and frank discussions on matters of mutual concern with the Japanese.--*Donald C. Shapero, National Academy of Sciences; Robert C. Pohanka, ONR; and Sachio Yamamoto, ONRASIA*

* * * * *

COMPUTING IN HONG KONG

Computing activities in Hong Kong are described.

by David K. Kahaner

INTRODUCTION AND SUMMARY

China (including Taiwan and Hong Kong) has almost 1.3 billion people, 5 to 6 times the population of the United States, and more than 10 times the population of Japan.

Both Taiwan and mainland China consider themselves part of one country, although there is a small difference of opinion as to who is in charge. We presented a report on computing in Taiwan in an earlier issue of the *Scientific Information Bulletin* [see "Computing in Taiwan," 16(2), 23-29 (1991)], and on page 17 of this issue is an article discussing mainland China explicitly. This report is limited to Hong Kong.

Comprising over 200 small islands and a section of the Chinese mainland, Hong Kong has been under British control for 149 years. Hong Kong Island is the best known of these islands and the location of a spectacular array of large, modern skyscrapers, dominated by the Bank of China Building, and Victoria Peak, the latter the location of former British summer residences. The adjacent mainland portion (Kowloon) is another tourist center, packed with hotels and shops.

Hong Kong will revert to China in 1997. At the moment it is officially under British control. There are the expected disputes between Britain and China about how much money should be left in Hong Kong's treasury, who should make decisions concerning contracts that overlap 1997, etc. Plans to construct a new multibillion dollar international airport were the focus of this controversy while I was there, with China, Britain, and Hong Kong all claiming they had the right to have final say. Among Hong Kong's population, there are differing points of view on this transition. Most of the professionals are apprehensive because of the uncertainty, while some feel that ultimately it will be a good thing to be united. But many industrial firms are packing up and moving, and there has also been a well publicized exodus of Hong Kong citizens to Canada and other hospitable countries. Other people are hedging their bets and attempting to obtain foreign passports with the hope that they won't be forced to use them. One Hong Kong scientist asked me if I knew how he could get a British passport (I didn't). Britain has set up a quota system for a limited number of British passports depending on age, education, and vocation of the applicants. Apparently there is an excess of some scientists and engineers who have applied, and not enough managers. I was told a story about 2,000 well-to-do (and shrewd) Hong Kong citizens who purchased East German passports shortly before Germany was reunited. The general feeling was very well expressed by one scientist, who put it this way, "we are hoping for the best and preparing for the worst." The nearby Portuguese-run peninsula of Macau, and two outlying islands that are part of the Macau colony, will revert to Chinese control in 1999, 2 years after Hong Kong.

Computing and related research in Hong Kong is fragmented, with individual universities going their own way; laissez faire is a good way to describe the state. This might equally apply to other aspects of activities within Hong Kong, which appears to be the ultimate "free market." There is a great deal of creative energy, especially at the University of Hong Kong, but I had very little sense that there were any coordinated programs among the universities. This assessment is tentative, however, as I had no opportunity to speak to government officials who might be promoting such things. Also, the situation might change as Hong Kong's new Science and Technology University begins operation; the government has identified information technology as a key area on which this university should focus. Nevertheless, the computing world here is quite different from, say, Singapore [see my previous article, "Computing and Related Scientific Activities in Singapore," *Scientific Information Bulletin* 16(3), 53-63 (1991)], in which coordination is dramatically apparent. About 3 years ago a study was commissioned to determine if the Hong Kong Government could justify the purchase of a supercomputer for use at the universities and other public facilities. That study concluded that such a purchase was not justified at the time, although perhaps there was also some concern about where this machine would ultimately end up. The study went further and suggested that a small super would be a good option (I felt the same). The Hong Kong Government decided not to pursue this.

There are seven main college/universities in Hong Kong, and they come under the University and

Polytechnic Grants Committee (UPGC). This is a British setup to ensure academic freedom from government influence. Similar committees are found in Britain and New Zealand. The UPGC office is staffed by civil servants, and they can help with arranging appointments with committee members.

While all universities and colleges in Hong Kong are publicly funded, the funding is not decided by the civil servants. Rather, a committee has been set up consisting of local and overseas academics and local businessmen and industrialists. This committee oversees the funding (including research) for all seven universities and colleges. The committee members are the policy makers. If you visit UPGC you will get an overall picture of the present situation and the future plans of computing in Hong Kong.

The government also has a Government Data Processing Agency (GDPA) that both handles large-scale computation for all government departments and oversees computing policy within the government. Finally there is the Hong Kong Trade Development Council (HKTDC) for industrial and manufacturing sites.

The general organizational concepts for the seven universities and colleges under UPGC are:

1. The University of Hong Kong (U-HK) and the Chinese University of Hong Kong are well-balanced, all-round universities.

2. Hong Kong University of Science and Technology (HKUS&T) is a brand new university that will open its doors to students in the fall of 1991. Its emphasis is on professional subjects.

3. The Hong Kong Polytechnic (HK-Poly) and The City Polytechnic of Hong Kong are vocationally oriented colleges. The goal is that eventually three-quarters of the students will be degree candidates. (Hong Kong also has a number of "technical institutes" that offer diploma level vocational subjects. The level is equivalent to junior colleges in the United States.)

4. The Hong Kong Baptist College and Ling Nam College originally began as private institutions modeled after the U.S. liberal arts colleges. After they became publicly funded, the professional courses (mainly business and social service) were strengthened.

U-HK and Chinese U-HK have both graduate and undergraduate programs and have faculty members engaged in research. The remainder are more focused on vocational training and some postgraduate (mostly master's) programs. Their faculty also do some research.

I visited U-HK, HKUS&T, HK-Poly. All three are either bursting at the seams or in the midst of a frantic building program. I had no opportunity to visit Chinese U-HK, but I was told that this is a fairly traditional university that has heavy emphasis on the social sciences. U-HK, HK-Poly, and Chinese U-HK have enrollments in the range of 10,000-13,000, and HKUS&T is anticipating similar numbers within a few years. Hong Kong has a population of about 6,000,000, so there does not appear to be much doubt that this level can be maintained as long as the government provides financial support (these are all public institutions).

UNIVERSITY OF HONG KONG

U-HK is on Hong Kong Island, in a very hilly setting. Buildings are stacked, and it is difficult to walk more than a few meters in any direction without encountering steps. There are some beautiful views.

U-HK has a very active computer science (CS) department, established in 1988. I had met the chairman in Taiwan, where I was impressed with one of his research papers.

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The current department has about 15 faculty members. In the 1989-90 academic year, there were about 120 students, 43 CS undergraduates, 60 civil engineering undergraduates, and 14 graduate students. Almost all of the faculty have Ph.D. degrees from Western universities such as Princeton, Columbia, Waterloo, Wisconsin, Illinois, London, etc. Research interests span the usual range of those in computer science departments. I did not sense much activity in numerical computation and none in numerical analysis (I had no opportunity to visit the mathematics department), although at least one faculty member (W.W. Tsang) is interested in statistical computation. There is some work in parallel and distributed computation, related mostly to programming environments, networking, systems, and object-oriented programming. Chin's research that caught my attention in Taiwan was concerned with computation on a hypercube. It is somewhat theoretical and was done while he was on sabbatical in the United States. His current responsibilities leave little free time for research. There is a generous collection of modern Unix workstations, but I did not see any parallel computers at the university. There may be some at local industries, however.

The department has generated a credible number of publications, mostly in English, many in well known journals. There is an active visitor program. While I was there, Prof. Robert Uzgalis (retired from UCLA) was ending a year's visit. The university provided him with support and housing. Uzgalis claimed that the Chinese students he met were very creative and diligent and more suited for creating new software than some other Asian groups he had dealt with. He also commented that there was an excess of skilled computer talent in Hong Kong, and many graduates are forced to accept positions in financial or other fields. In fact, I did not see any evidence of an information industry, although I was told that there is at least one PC clone (Sigma) produced in Hong Kong. (The new HKUS&T has as one of its goals to build the information industry in Hong Kong.) However, while I was in Hong Kong I watched an exceptionally well done computer video that was presented on TV as an advertisement for the proposed new airport. It showed the bay surrounded by tall buildings, water disappearing and slowly being replaced by runways, followed by a 747 on its final approach and landing. Unfortunately, I was not able to get any information about where this was made.

HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

The most interesting new scientific development in Hong Kong is its new university, HKUS&T, which will consist of a grouping of professional schools emphasizing science, technology, engineering, management, and business. There is a deliberate decision to make the university focus on technology transfer to industry. In fact, there is a plan to create two separate types of positions to attract scientists from both the academic research community and the industrial/commercial research and development (R&D) sector. Initially, the teaching language will be English, but university administrators acknowledge that Chinese will also be pervasive to satisfy "a practical need for our graduates to be able to flourish up north." At the time of my visit, the university staff members were located in an office building one block from the center of the downtown portion of (the mainland-Kowloon) Hong Kong, but a brand new campus is being built outside central Hong Kong and is visualized as more like a college town than an urban campus, set along the ocean on 60 hectares, including not only the university complex but sports facilities, student residences for over 2,000, senior staff apartments of 1,500 to 2,000 ft^2, shops, etc.

Academic staff are being recruited actively. Senior members are being sought by all traditional methods including academic "head hunting." Advertisements in scientific journals are also used. I noticed a large ad in a recent *SIAM Newsletter*, indicating very handsome salaries and benefits. Many of these senior positions have now been filled, and there is a long list of scholars who have spent many years at very well known universities in the West, including Berkeley, Princeton, USC, CalTech, Brown, Oxford, MIT, and the like. Roughly two-thirds of the senior staff have Asian names; the remainder appear to be Western. The university reluctantly has acknowledged that they will have to pay department salary differentials based on market conditions.

There are many growing pains and some chaos as the first students will appear this fall. More than 10,000 applicants vied for about 560 undergraduate positions. The following year about 2,000 students are expected. Plans are to have about 10,000 students by the end of the decade. (Regardless of the long-term future of the university, I think that its first students will have a very rich and rewarding educational experience.)

Table 1 describes the planned enrollments. Within the School of Engineering, computer science and electrical engineering will be co-equal as the largest programs. Surprisingly, mathematics will eventually be the largest program in the School of Science, half again as large as physics, and almost twice as large as chemistry. Perhaps this is related to the strong mathematics faculty, of whom five have already been selected, including two professors from Brown (Hsieh and Shen), a former department head from Princeton (Hsiang), and a research mathematician who spent 20 years at the U.S. Naval Research Laboratory (Yang). The computer science program will be headed by a Princeton Ph.D. and former MCC program manager (Shen). The university president (Woo) was formerly president of San Francisco State University.

The university is planned to be a first class research establishment, and funding has already been secured for programs in biotechnology and information technology. There are a large number of additional proposals in areas such as advanced materials, energy, scientific computation, manufacturing, cognitive science, and others. A Materials Characterization Center, Microfabrication Center, Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) Laboratory, and others are being built. A computer environment is also being developed. It will consist of heterogeneous microprocessors such as micros and workstations, connected with a few large minis and mainframes via a fiber distributed data interface (FDDI) network. The network is in the form of a dual ring of trees; optical fiber will be routed to various central locations, and then Ethernet cables will connect to individual users. The net will not only be connected to offices but also to all campus housing. Some of this network is already installed. There is at least one HP 70-MIP workstation and many other workstations are presently in boxes waiting for installation. The university claims that every department will have or share a computer laboratory for use by graduate students and faculty, and every faculty member will have a workstation.

Well known software such as IMSL and SAS is installed and available through the computer center. The new campus will be connected to others in Hong Kong via a 9,600-baud line, and a T-1 line to Britain will be installed sometime in 1992. Plans are to link the university via real-time video and data paths to Asia, Europe (via London), and the United States (via California) to allow it "to become one of the most international of all the world's universities"! Certainly, the failed supercomputer for Hong Kong would have been very useful. As things stand now, users will have to find creative ways to use distributed workstations.

I have no special insight about the future prospects for this university. Unfortunately, I did not meet with senior members of the administration or the research faculty, but only with staff from Computer Services and one member of the new computer science department. At this point the university has no track record and only an energetic new faculty and developing physical plant. The university could become the high-class research center that it hopes to be. Mostly it will depend on the commitment of the Chinese Government to maintain the path set out by university founders, as well as that government's ability to sustain the university's financial requirements. For senior Western scientists who have joined the faculty, I believe that things are more clear. Most of these people are in the later stages of their professional careers and the university now has more than enough momentum to carry them along for a number of years. The same would be true for visitors. It will be interesting, though, to see how successful the university is at recruiting mid-career faculty, and it will be important to follow progress here during the coming decade.

My primary contact at HKUS&T is

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His address and telephone number will change within the next few months as the new campus is opened.

THE HONG KONG POLYTECHNIC

HK-Poly is within walking distance of the center of Kowloon, thus an urban campus, which is being expanded. As mentioned above, HK-Poly is more of a vocational center than a research university. Nevertheless, it has about 13,000 students, although only about 60% are degree candidates. I met with

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HK-Poly's computing facilities include about eight Vax 11/780s or equivalents, some PCs, and terminals. There are no Unix workstations yet. Software includes ACSL (for system simulation, including solution of differential equations), IMSL, GLIM, Ansys, LP/Protran, Macsyma, SAS, SPSS, AutoCAD, various database products such as Oracle, and a fair selection of graphics software such as Movie, Gino, etc. As usual, the computer center is overworked and understaffed. I had no opportunity to speak with any members of the scientific faculty.

Table 1. Planned Enrollments

[Figures are for undergraduates/graduate students/faculty and staff.]

School	1991	1993	1995	1999
Science	180/30/49	835/130/129	1503/365/192	2024/430/263
Engineering	230/42/39	1054/126/120	2070/433/209	3192/726/317
Business & Management	150/60/31	1034/210/104	1963/474/161	2798/627/226
Humanities & Social Sciences	0/ 8/15	0/ 61/ 50	0/155/ 80	0/200/110

All these schools are connected together via electronic networking (Harnet: Hong Kong Academic & Research Network). The individual nodes are connected either by leased/ dedicated circuits or through the Hong Kong Telephone Company DATAPAK service. There is a common gateway for access to international networks. Interestingly, there is a printed directory of electronic mail users that integrates all the universities (very helpful). This might be available on-line as well.

ROYAL OBSERVATORY

The main contact at the observatory is

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This observatory, with a staff of 300, is a department of the Hong Kong Government that primarily operates weather forecasting, cyclone warning, and related meteorological and geophysical services. The main facility stands on a wooded hill in the center of downtown Kowloon. In crowded Hong Kong the land value alone must be astronomical. The administration is housed in a beautiful British colonial building dating from the 19th century, and one expects to see white-suited, mustached men with cold drinks sitting on the veranda. In many ways the observatory is a world apart from the frantic activity in most other parts of Hong Kong.

Various weather information is collected from ships, weather buoys, aircraft, and island and land stations, and data (including video) are also transmitted by weather satellites and microwave. This includes such things as air and sea soundings (wind, temperature, pressure, humidity, solar radiation, evaporation, evapotranspiration, sea temperatures, sea waves, tides, etc.), radar, microwave cloud pictures, rainfall, and others. A Royal Navy officer is attached to the observatory to act as a liaison with Navy ships in the China Seas and western Pacific. The observatory is also responsible for coordinating marine data for the South China Sea. Advice on marine climatological conditions is given to various companies, especially those engaged in offshore oil activities. Staff members from the observatory also teach courses in atmospheric science at Hong Kong universities.

The main activities of the observatory are as follows:

- Record keeping and climatological services.
- Radioactivity monitoring and assessment in order to determine background radiation levels in conjunction with Daya Bay Nuclear Power Station. There is also a Monitoring and Assessment Center.
- Time service based on Caesium Beam Atomic Clock and broadcast by various radio stations.
- Geophysics and astronomy, primarily to monitor earthquake activity and gravimetric measurements, via seismometers, accelerographs, etc.
- Hydrometeorology, mostly via raingauges for water resources information and flood forecasting models.
- Oceanography, including storm surge simulation, tidal monitoring and modeling, and wave and swell numerical models.
- Applied meteorology, effect of terrain on wind flow and participates, and in particular various studies related to locating the new Hong Kong airport.

Generally, weather-related activities account for about 90% of the observatory's expenditures ($10-15M U.S.).

There are communications links between the observatory and meteorological centers in Tokyo, Bangkok, and Beijing (9600 baud). All together, these amount to 4-5 MB/day. These data, plus that generated locally, are processed into various charts and forecasts. Most of the computing is being handled by several minicomputers, such as Data General Eclipse S/140, MV20000, etc. There is a substantial amount of data acquisition, plotting, display, and tape archival equipment. Databased weather data amount to about 300 MB/yr, and Oracle is the main database product in use. There were two IBM RS/6000 Unix workstations in crates yet to be installed when I visited. The observatory decided to purchase these after the decision was made not to obtain a supercomputer for Hong Kong. The staff is heavily involved in day-to-day forecasting but would like to do more serious numerical modeling, and a small supercomputer maintained elsewhere would have been ideal. The IBMs will also be useful but will require maintenance and training. These will be the first Unix machines at the observatory.

More computer horsepower will also enable them to work on image enhancement techniques, computer animation, etc. Storm surge models have been carried out at the National Oceanic and Atmospheric Administration (NOAA), and a single layer vertically integrated bay model has been run at the observatory. The staff would like to increase this to a multilayer model as well as to perform various finite element computations. Hong Kong weather is subject to the vagaries of both tropical and extratropical weather systems as well as Asian monsoons. Hilly terrain and large land/sea contrasts give rise to complex small-scale atmospheric circulations, leading to significant local weather variations. Some very interesting modeling is being done using a limited area model developed by the Japan Meteorological Agency. On current computers this is run once each day to give forecasts up to 2 days ahead. Some of this computation will be very much improved with the new workstations.

Observatory staff do not appear to be active in research, although there are clearly many fascinating topics that could be examined. I also did not get the impression that there was much collaborative activity between the observatory and universities in Hong Kong, even though there is an active international meteorological community with which they interact. There is no electronic mail, a serious deficiency, and until recently not enough computer power for significant numerical research. Nevertheless, the observatory has many interesting problems, a long scholarly history, and a wonderful setting. I think that the new HKUS&T would be well served by developing some cooperative projects.

ACKNOWLEDGMENT

Helpful and extensive comments were provided by K. Kenneth Lo, Goddard Institute for Space Studies, who can be reached on Email at cdkkl@nasagiss.bitnet.

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FUZZY HELICOPTER FLIGHT CONTROL

This article summarizes research on helicopter flight control in Japan based on fuzzy logic techniques.

by David K. Kahaner and Daniel G. Schwartz

INTRODUCTION

During the past year I have electronically circulated several reports on research in fuzzy systems (control.34, 1 Aug 1990; takagi, 7 Aug 1990; fuzzy, 24 Aug 1990; fuzzy.gmd, 21 Jan 1991; klir, 12 Apr 1991; and fuzzyl.gmd, 17 May 1991). Some of these reports have also been published in the *Scientific Information Bulletin* [D.K. Kahaner, "Fuzzy Logic," **16**(1), 41-47 (1991); T. Hagemann, "Second Fuzzy Logic Systems Institute Hardware Practice Seminar," in "Scientific Information Briefs," **16**(2), 2-3 (1991); G.J. Klir, "Japanese Advances in Fuzzy Theory and Applications," **16**(3), 65-74 (1991); and T. Hagemann, "Omron's Fuzzy Technology Business Promotion Center," **16**(3), 75-79 (1991)]. During the summer of 1991, the Office of Naval Research supported

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to analyze Japanese research in this area. Schwartz will be preparing a report that I will circulate as soon as it is complete (look for an article in a future issue of the *Bulletin*). However, the following material is interesting enough that we felt it was appropriate to circulate quickly. More details will follow as part of Schwartz's report.

This article concerns three projects related to helicopter control that use fuzzy logic; we are not aware of any comparable research in the United States. There seems to be some sense among Japanese researchers that research on fuzzy theory (basic science) may be losing some of its momentum, but applications (engineering) are still very active. It is our opinion that in the United States, applications of fuzzy control to real problems are far behind the work in Japan.

SUGENO'S PROJECTS

In several of the earlier reports we mentioned research on the use of fuzzy control for helicopter applications. For example, at the 1989 Japan electronics show, a small model helicopter with several rotors was demonstrated. This was developed as a Laboratory for International Fuzzy Engineering Research (LIFE) project. However, the model was very small, and most of the information was obtained by cameras on the ground. The information from these cameras was then fed to a ground-based control system helping a human operator, who held a set of wireless controls.

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described three more recent projects of his, in this general area:

(1) Radio control of helicopter by oral instructions

(2) Automatic helicopter autorotation entry

(3) Unmanned helicopter for sea rescue

The projects have some overlap.

In 1989, the Science and Technology Agency (STA) (part of the Prime Minister's office) began a 5-year program, Fuzzy Systems and Their Application to Human and Natural Problems, covering three major areas.

- Basic theory (inference, fuzzy computer, operating system, etc.)
- Engineering
- Applications of fuzzy theory to social and natural science

The actual projects are as follows:

1. Fuzzy Logic
2. Algorithms and Fuzzy Reasoning
3. Programming Languages and Architecture
4. Intelligent Control of High-Speed and Unstable Systems
5. Intelligent Control of Ill Structured Systems
6. Real Time Image Understanding (Fuzzy-Neural Systems)

7. Recognition of Hand-Written Letters
8. Modelling of Sensual Information Processing (Image and Sensors)
9. Human Interface in Home Automation
10. Human Interface for High-Speed and Unstable Machines
11. Evaluation of Complex Systems
12. Fuzzy Information Retrieval
13. Fuzzy Association
14. Evaluation of Reliability of Large Scale Systems
15. Application of Fuzzy Logic to Social and Management Systems
16. Earthquake Forecasting
17. Prediction of Air Pollution in Wide Area
18. Modelling of Plant Growth

In total, these projects are worked on by about 60 researchers at 19 different organizations, roughly one-third each at academic, industrial, and government laboratories. Its total budget is about ¥0.8B for 5 years, about $1M/yr. Sugeno explained to us that this program is actually larger than LIFE's, as it does not have to cover salaries, and because there is no central facility to be operated. There was a closed symposium last year and he has promised to send us a copy of the proceedings, although it will be in Japanese. There will be another symposium this year, after an international meeting on fuzzy systems in Japan (November 1991), and we were told that at least one day of that will be open.

Sugeno's projects are being supported as follows:

(1) 1989-1993, TIT and STA. There are two graduate students working on this. Until recently the project was conducted at TIT, although it has moved to a site near Osaka.

(2) 1989-1993, TIT, STA, and Kawasaki Heavy Industry. There are five or six engineers working on this at Kawasaki. This is the company that manufactures the body for Boeing's 747 and also builds at least one large helicopter (BK117).

(3) 1990-1991, TIT, Tokimec and the Ministry of Transportation. Tokimec is a large instrument company (sensors).

Projects 1 and 2 are supported under the engineering part of the STA program. Project 3 is supported by the Ministry of Transportation.

Project (1). The goal is to be able to use simple language, "fly straight," "turn left," "hover," "land," etc., for control. Sugeno had already done this with a car more than 5 years ago. Of course, the current project is vastly more complex. They developed a 1-meter model that was able to correctly respond to "take off" and "hover". They are now using a 3.5-meter model (adapted from Kawasaki's R50) and they have been able to make this respond stably to "hover"; this month they will also be testing its ability to respond to commands to fly straight. Sugeno explained that the model cost about ¥12M (almost $120K), of which about ¥7M are sensors, and that the size, danger, and cost of the system required them to move the project out of the university.

Sugeno explained that there are 15 state variables for the helicopter: three spatial coordinates, their velocities and accelerations, three angular coordinates, and their speeds. Of these, currently only nine can be measured on the helicopter; spatial position and velocity need to be measured from Global Positioning System (GPS) satellite data that are not yet readily available in Japan, although he claims that within 3 years there will be enough of these satellites in orbit to provide the additional needed data.

Motion of the helicopter comes from making adjustments to collective pitch level, longitudinal stick, lateral stick, and directional pedal. General linguistic (high level) rules can be formulated such as "while hovering if the body rolls, then control the lateral in reverse," etc., and that these can then be converted into a number of fuzzy rules, such as "if delta x is Forward then delta longitudinal stick is Pull." In all, they generated about 120 rules, which then replaced the usual proportional integral derivative (PID) controllers in the helicopter. As described above, they have run actual tests with the models using several (not all) of the voice controls. In addition, they have simulated all the controls that they plan to implement using a Silicon Graphics 3D workstation. Sugeno displayed some of the simulation results showing plots of air speed, altitude, pitch, etc., during various situations such as variable wind of 7 to 13 m/s from one side while hovering and claimed that the plots were as good as would be obtained from manual control with an experienced pilot. Sugeno is confident that the project will eventually be able to actually operate a real helicopter using these techniques.

Project (2). As Sugeno explained, when a helicopter has an engine failure the pilot must decide if he should (a) try to restart the engine or (b) abandon the attempt. In the latter case he must disconnect the engine from the rotor to allow it to rotate freely and then dive forward in an appropriate manner to generate force on the rotor to keep it spinning. If this is done correctly, then near the ground he can straighten out and there will be enough lift on the rotors to allow a safe landing. Sugeno explained that all pilots must have this skill to obtain a license. A key aspect of this is "autorotation entry," the period between straight flight when the engine fails and initializing the dive, and pilots at Kawasaki told him they did not think it could be automated. However, again using a fuzzy control system, he claimed that it had been done, and in fact it was going to be installed on the company's large units. (We did not obtain any of the details of the fuzzy rules.)

Project (3). This project is much larger than either 1 or 2 and will not be finished in the allowed time; Sugeno is expecting that it will be continued. The main goal is to allow a helicopter to fly from a mother ship to another location, for example, where a ship is on fire, and perform various operations, such as rescue. The original project was to combine GPS satellite data with other video information to generate traditional control instructions from the mother ship, but Sugeno is anticipating that the project follow-on will replace this with fuzzy control.

CONCLUSION

Sugeno explained that the Japanese feel they have worked out all the necessary theory associated with fuzzy control; of course, there are many applications yet to be developed. He felt that there were two major problem areas to be studied in the future: (1) control of unstable systems of which the helicopter is a prime example and (2) control of "ill structured" systems, those too large or poorly defined to be amenable to traditional methods (he specifically mentioned control of water turbidity in a filtration plant and some biomedical systems). In response to a query about chaining of fuzzy inferences, Sugeno explained that while this is not done formally it is done in practice by first using what he termed fuzzy-sensors followed by a fuzzy inference. Fuzzy-sensors refers to making decisions about sensor inputs by fuzzy reasoning, such as "why is the water turbid" (oil, dirt, etc.).

Daniel G. Schwartz is an associate professor in the Department of Computer Science at Florida State University, Tallahassee. He holds B.A. and M.S. degrees in mathematics, and he completed his Ph.D. in systems science at Portland State University in 1981. His dissertation and subsequent research concerned formal axiomatizations of fuzzy logic and associated reasoning systems, whereas his more recent work has involved the development of a new symbolic approach to approximate reasoning. Dr. Schwartz has over 30 published articles on these and related topics. His current interests include the integration of fuzzy rule-based reasoning with other reasoning paradigms and their applications both in expert decision support systems and in automated control.

COMPUTING AND RELATED SCIENCE AND TECHNOLOGY ACTIVITIES IN CHINA

This article provides an overview of computing and related science and technology (S&T) activities in China.

by David K. Kahaner

INTRODUCTION AND SUMMARY

This report is a complement to my earlier article on Chinese computing ["Computing in Taiwan," 16(2), 23-29 (1991)] and to two articles that appear in this issue ("Computing in Hong Kong," on page 7, and "The Second International Conference on Numerical Optimization and Its Applications," on page 25). It is based on one visit to China [the People's Republic of China (PRC)] during June 1991 and on some English literature and English translations.

In many ways, mainland China (PRC) is a modern, industrial nation, and in others it is a poor, third-world country. High-tech industries in China are struggling because of the usual problems associated with partially developed countries. There are additional problems related to restrictions on trade from the United States and European Community (EC) because of political differences. Lack of good communication facilities such as computer networks and fax machines means that information flow is erratic; several of the scientists we spoke to were unaware of activities in neighboring Chinese institutions, while others appeared to be exceptionally well connected. Electronic mail is just beginning to appear. Access to computers is generally erratic. There is a heavy emphasis on simulation and theory when experimentation might be better. Basic theoretical research (pencil and paper) is excellent, especially in applied mathematical analysis. We saw no parallel computing activity, although available reference materials indicate that some work is in progress. We were not able to assess research in computer science either, except it was clear that computer engineering is very active. Fuzzy logic, for example, has a tremendous following, and there are a great many applications being developed for industrial processes, perhaps more than in the United States. (See the anecdotal list of applications given below.)

Access to Western research information also appears spotty. Some lectures at a conference we attended in Xi'an suggested a very out-of-date view of Western literature. On the other hand, senior scientists travel to and study in the West and read and write English fairly well. But many Chinese scientists have not travelled outside of their country and have not had much opportunity to use spoken English. There also appears to be substantial library facilities at least at some institutions. Communicating in English seems to be more of a problem than in Japan, but this is also very variable.

There is no doubt that China is trying very hard to push science and technology as a means to move itself forward. Numerous studies have emphasized that the country that invented paper, movable type, gunpowder, and the compass has had no similar scientific achievements in recent times. Four volumes of "S&T white papers" have been published since 1986 describing the Chinese Government's significant policy and strategy decisions, related materials, and regulations for scientists and others. It is hoped, for example, that by the year 2000 high-tech industries will become pillars of China's national economy, traditional industries will improve their productivity, the internal consumer market will fuel other improvements, and even military research institutes will shift strategically toward civilian products, as is now occurring in the Soviet Union.

Thus there is plenty of interest, ample reports, and relatively large quantities of money to be spent on research and development (R&D), although it must be spread over a huge infrastructure. For example, the State Science and Technology Commission will funnel over $2B into high-tech development during the 1990s. For better or worse, China has over 7,500 scientific research organizations at the county level or above, a high-tech work force of more than 3 million including about 400,000 scientific research personnel, almost as many as in the United States or Japan, and more than in England. Many of the policies for promoting S&T are common to other industrializing countries and will not be detailed here. A typical quote is:

> We should strengthen reverse engineering and digest, absorb, improve, and develop imported technology; take advantage of our vast population; and raise design starting points. An example is importing and digesting French engine technologies as a basis for reverse design and absorbing new engine technologies from foreign countries for development and innovation to design and develop our own new type of engine...

At the same time that the Chinese Government is trying to open itself to the international scientific community, there is also a substantial amount of old-line inertia and flowery governmental prose in published documents. This is compounded by official concerns about giving away secrets to foreign intelligence agents. However, all the experiences during our recent visit suggest that individual Chinese scientists are just as eager as those anywhere to engage in cooperation and free scientific information exchange. Let us do everything possible to encourage and support this attitude.

CHINESE KEY NATIONAL LABORATORIES

A plan to build national key laboratories in universities and research institutes began in 1984. The focus has been on building and operating open laboratories, setting up a new research system, promoting collaboration and cooperation, building up personnel, establishing a good academic atmosphere, and managing the laboratories. More than 60 national laboratories have been built since 1984. In addition, the Chinese Academy of Science (CAS) also has invested in setting up a similar number of academic laboratories and institutes that are university-like (including some students) but in a different organizational chain. Further, more laboratories have been proposed so that there could be on the order of 150 by 1995.

The Chinese Government is now focusing on the fact that building a high class laboratory involves not only a large one-time construction cost but a high ongoing operational cost. There is now a trend to consolidate some laboratories to make their operations more cost effective, make research funds less diffuse, and make sure that research directions are not divided too finely. There are still many problems related to "turf," and cooperation as well as communication between laboratories needs improving. There are also a number of issues related to personnel, such as getting laboratory leaders of international stature (the target here is the Cavendish Laboratory with Maxwell and Rayleigh as early directors) and getting (and keeping) enough young researchers and support technicians who will make most of the actual breakthroughs. Of course, the perennial problem of logistic support occurs, too. To operate the laboratories it is recommended that "operation is more important than construction," "academic atmosphere is more important than current academic standard," and "management is more important than current experimental condition."

863 PLAN

This is the major plan for S&T development, proposed in March 1986 (86 = 1986, 3 = March). It is centered around five areas, with its main focus to catch up with advanced technology. Five areas are of special interest.

- Biotechnology.
- Information technology (see below).
- Automation technology (especially a demonstration production line at Qinghua University; comprehensive automated manufacturing systems; high performance sensor technology; multiphase system control technology; and robots for precision work, work beyond 300 meters depth, and work in difficult environments).
- New materials (especially for high temperature and shock resistance, high malleability, for power equipment, aerospace materials, micromaterials, thermoplastic resins, ceramic-base, semiconductor photoelectric, optical memory, artificial crystals, membrane materials, noncrystalline, superconducting materials, etc., to the late 1980s levels).
- Energy resource technology. The Chinese Government has also initiated a "Torch Program" to ensure that any advances of 863 will be put into commercial/industrial use.

INFORMATION TECHNOLOGY (IT)

A large number of articles in the Chinese official, popular, and technical literature have emphasized the importance of IT as part of China's High Technology Development Plan, also called 863 Plan (see above). In some articles IT is described as the most important of all the 863 projects. The IT aspects are divided into three general areas.

- Information acquisition. The plan is to develop a broad variety of information acquisition and processing technologies for industrial and agricultural needs, especially in the areas of infrared detection, adaptive optical telescopes, imaging radar technology (including satellite-carried synthetic aperture radar and infrared focal plane technology), high speed real-time signal processing, and graphics.

- Optoelectronics. The plan is to develop all kinds of novel optoelectronic devices and associated system integration technology for sensing, computing, and communications and to study new ways to fabricate very large scale integration (VLSI) in order to lay the technical and material groundwork for new information acquisition systems, computers, and communication equipment. It is generally accepted in China that if the 20th century is the era of electronic information, then the 21st will be the era of optoelectronic information.

- Intelligent computing. The plan is to put the best people and resources in advanced computer technology and artificial intelligence (AI) together to track the latest developments in the world, investigate the theoretical basis and key technology of intelligent computers, and promote the widespread use of AI to push for an intelligent computer industry in China. Processing Chinese characters is an important part of many projects associated with intelligent computing.

All together there are about 300 projects, 2,500 scientists and technicians, and about 80 organizations. The Chinese are definitely attempting to pool resources into national research centers. For example, the intelligent computing work has been centered in the CAS Institute of Computing Technology. About one-third of the projects have been completed, and the Chinese estimate that about one-quarter of these are competitive with international scientific standards.

The Chinese have stated that

> We should encourage international joint R&D activities and strengthen cooperation among open laboratories, research centers, research institutes, and higher learning institutions in China. A unified, orderly, competitive, and mutually complementary network of cooperation should be established.

There is also great interest in having visiting researchers as well as sending Chinese students to other countries. For this, as well as other international activities, however, some nontechnical issues are also relevant. For example, "We must intensify their ideological and political education to firm up their patriotism, national pride and confidence, and faith in socialism," etc. As of September 1990, the Chinese Government has broken out its information technology project accomplishments as shown in Table 1.

The descriptions below attempt to give a very brief picture of some of these projects. The remarks are fragmented and have all been gathered from available documentation. I have not had personal contact with these projects, so the descriptions may not be accurate. I should note that the Chinese scientists I spoke with were frank and realistic about the status of their work. But in print, projects are often described in exceptionally positive terms. This is especially true for summary reports. If readers are interested I will attempt to obtain further information about selected projects.

Table 1. The Chinese Government's Accomplishments of Its Information Technology Project

Topic	World Level	Domestic Leader	Intermediate Results	Design Final	Disseminate Applications	Total
Intelligent Computing	12	35	21	21	5	47
Optoelectronics	7	31	33	3	2	38
Information Acquisition & Processing	3	10	8	0	5	13
Total	22	76	62	24	12	98

COMPUTING, GENERAL

It is estimated that there are about half a million PC-type computers in China, with about two-thirds of Chinese manufacture, compared to about 25% in 1981. In 1985 about $1.2B was spent on computer imports; in 1989 this had been reduced to $389M. It is now hoped that Chinese systems can be exported, perhaps up to $1B by 1995. Production includes complete systems, peripherals, monitors, printers, magnetic recording equipment, as well as system and application software. A major thrust of work has been input of Chinese characters. Computers manufactured in China are marketed under the names of Great Wall, Taiji, Zijin, and Legend. For example, Legend [Beijing Legend Computer Group, part of the Chinese Academy of Science (CAS)] markets 286, 386, 386SX, and 486 systems. A 386 system (33 MHz) has also been developed by CAS, with a 66-Mbit/s transfer rate between memory and CPU and a RISC-based floating point unit. This system can be purchased with an independently designed 1280x1024 color card. In 1990 about 100K 286 motherboards were shipped to the United States and Europe. China's first electron tube calculators were also made at CAS in 1958--a copy of a Soviet model; current production uses LSI technology. Changzou Electronic Computer Plant also markets a laptop based on a 4.77-MHz 80C88 and supports both Chinese and standard ASCII characters. Another model uses memory card technology based on an independently designed and developed card.

To the best of my knowledge, China currently has no Western supercomputers. However, I was told last fall by representatives of Convex Computer that there were several sales close to finalization, and in March 1991 it was announced that four C120 Convex minisupers were approved for sale to arrive in late spring. Applications for these computers are seismological, petroleum prospecting, simulation of oil reserves, and weather. I do not know exactly where these systems are going.

NEURAL NETS/ EXPERT SYSTEMS

China's first neural net conference was held in December 1990 in Beijing with representation from 100 Chinese institutions resulting in over 350 technical papers in the proceedings.

The CAS Institute of Automation reports that they have applied a neural net model to diagnosing reactor faults and have actually used this in practice.

Naval Academy of Engineering professors have been promoting the use of neural nets for inference engines, claiming that they can be more flexible and fault-tolerant and are more natural for learning. They have also published very basic theoretical results on new learning algorithms for multilayered nets that can find global minimums. Other work has shown by simulation (on digitized data of the silhouette of a U.S. Naval and a Soviet Naval ship) that a simple neural net can be used for ship silhouette recognition independent of translation, scale, rotation, or aspect changes.

CAS scientists have developed a Chinese speech recognition system using artificial neural net concepts and including a voice-operated text input system capable of recognizing over 20K dictionary entries. It is claimed that tone-recognition is over 99% and word-recognition is over 90%, even with compound words.

CAS researchers have developed a general-purpose expert-system language, TUILI, which can be referenced from either C or Prolog and is claimed to be superior to Prolog.

Qinghua University has a Chinese character recognition system (THOCR-90) that can handle various fonts, alphabets, numbers, and other symbols and employs neural net techniques for pattern matching. Recognition speed is about 30 characters/second on a 386/33. Another (somewhat faster) system has been developed at Nankai University.

FUZZY

Work in this area has been active since 1979. There have been numerous practical applications and research results reported, perhaps more than in any other country outside of Japan. In 1987 Chinese scientists presented almost one-quarter of the papers at an international fuzzy society conference in Japan, equal to those presented by Japanese attendees. Further, I was told that the (U.S.) *Journal of Fuzzy Sets and Systems* is being flooded with papers from Chinese scientists. In China, some specific applications include the following (these are all anecdotal).

- The CAS Institute of Semiconductors has built almost 2 dozen multilogic circuits (two-value, multivalue, continuous-value, e.g., fuzzy). Chinese researchers are very much aware of work in Japan by Yamakawa, who has built fuzzy logic circuits using CMOS technology, and in fact two researchers from Tsinghua University (Beijing) report that they have also built (using 5-micron CMOS) various basic circuits that they claim are simpler and more reliable than Yamakawa's.

- The Electronics Industry Computing Center has developed a fuzzy information processing command decision support system designed specifically for use in communications networks used for military command decision support.

- The Mathematics Department of Beijing Teachers' University (BTU) developed a fuzzy inference engine capable of 15M inferences/second. BTU has also built hardware claimed to be able to handle 30K (sic) basic rules with 2,000 input/output variables for fuzzy-based inference and that products are being marketed this year.

- Beijing Normal University has proposed a new method for fuzzy inference, called Truth-Valued Flow Inference, which they claim can represent knowledge more effectively than traditional fuzzy inference.

- North China Industrial University (NCIU) did a 6-year study on microcomputer fuzzy control theory and applications.

- Various papers on fuzzy control simulation and adaptiveness of fuzzy control have been published.

- The Staff & Workers College of the Shanghai Instrument and Meter Industrial Company has developed a proportionality-factor-type fuzzy controller and a three-loop fuzzy controller.

- Hunan University is using fuzzy composite control in gas smelter control systems.

- The Wuha Fist Science Research Institute of Light Industry has a fuzzy control system for glass kilns.

- The Handran Resin Plant has a fuzzy control system for the polyvinylchloride (PVC) resin polymerization process.

- The University of Petroleum used fuzzy control in large hysteresis systems for chemical engineering processes.

- The Chemical Fertilizer Industrial Institute, Jilin Industrial University, and the Metal Products Institute have used fuzzy control for compressor regulation, power factor compensation, dc reversible-speed regulation, and a digital dual-frequency-channel amplitude frequency instrument.

- The Air Force Institute of Engineering developed a fuzzy quantitative evaluation expert system for aircraft maintenance.

- Nanjing University uses fuzzy theory to analyze evaluation of sound quality in high-fi sound systems.

- The Armed Forces Economic Institute used natural fuzzy language in expert systems.

- The Zhenjiang Shipping Institute used dBASE III to develop a fuzzy database inquiry system.

- The Central China University of S&T has used fuzzy quantization in knowledge engineering.

- The University of S&T for National Defense developed a printed circuit board (PCB) logic diagram/manuscript pattern-recognition system in C, using fuzzy relations among text areas. On a PC-AT it is claimed to have a speed of 912 characters/minute and an accuracy of 98.9%. Another institute has also used fuzzy techniques and has a complete system including software and scanner for installation on a variety of micros.

It is not possible to know just how successful these projects have been as their descriptions are often brief, but the point is that Chinese scientists are exploring applications aggressively. At the same time there does not appear to be much emphasis on basic research for its own sake in this area.

PARALLEL PROCESSING

My visit did not lead to learning about any parallel computing except for old ELXSI systems that appeared to be not seriously used, but the literature does describe several projects of potential interest.

Wuhan Digital Engineering Research Institute developed the 980 STAR systolic array computer. This is composed of a host (Intel 310/286), image subsystem, interface processor, and systolic computing array. The latter consists of a 4x4 matrix of cells. Pipeline beat is 200 ns, and each cell is capable of 10 MIPS. Maximum throughput is 80 MB/s. Various system software has also been developed. This is considered mid-1980s technology. A new model is currently being developed and is claimed to have 100 times greater performance.

Programming on China's YH-1 (Galaxy-1) supercomputer has been via vectorized Fortran. (I am trying to learn more about this.) Current work is also in progress to develop a parallel programming capability, centered on C. There is also research on analyzing blocks of vector Fortran for vector block dependencies and a Pascal scheduler has been developed. It is claimed that some Cray-1 calls such as VF.MUL (vector float multiply) can be reduced from 644 to 381 beats. The Galaxy is a 100-MIPS machine. One specific application has been for processing seismological data from sections taken from petroleum prospecting areas.

The East China Institute of Computing Technology has a microcomputer parallel processing system based on 12 Inmos T800 transputers grouped into three clusters (boards) and connected to a PC-AT. One processor on each cluster is the main control processor. Peak performance is 80 MIPS or 10 MFLOPS.

Jiangnam Institute has developed and marketed a PC board insert with an

Inmos transputer and 8-MB RAM and software for development.

Qinghua University has developed boards with one, two, or four transputers (TTH-1A, -2A, and -4A) that will plug into PC-ATs and also has developed a transputer development system. These products are claimed to be fully compatible with European transputers at the late 1980s level.

Shantou and Nanjing University researchers have built an eight-processor parallel computer (Transcube) built around eight Inmos T414 transputers and an additional 1 MB of memory on each processor. The eight processing elements (PEs) are the bottom layer of the three-layer system, in which the top layer is the PC-AT host and the middle layer is an interface buffer controller. The researchers claim that it is easy to expand the system beyond eight PEs.

Graduate students at a research institute of the Ministry of Machine-*Building & Electronics Industry* have used two TI DSP chips to design a real-time parallel signal processing circuit for a pulse doppler ground surveillance (moving target) radar. They claim to have solved two key problems that had caused bottlenecks related to data input and synchronous coordination of both chips and that the system performs at 20M multiplications/additions per second and consumes 5 watts.

Fudan University researchers have developed a sea-wave processing system based on diffraction analysis of sea-waves. The system (which runs on an XT) can estimate the spectrum of a two-dimensional (2D) 512x512 image array with 16 azimuthal inputs in 9 minutes with a wave direction accuracy of 6° and 18 minutes for 32 inputs and an accuracy of 3°.

SOFTWARE

RT/VMS is a Chinese-developed, military, real-time operating system. The Chinese military feels that a major threat of future wars will be from computer viruses, rather than traditional weapons, and there has been a substantial effort to study and eliminate computer viruses within China. (Frankly I had not thought about this before, but it is an intriguing view.) RT/VMS is claimed to have innovations in channel interfacing, job scheduling, low system overhead, and hardware debugging technology.

The Commission of Science, Technology, and Industry for National Defense has developed an Ada compiler (in C), which is claimed to be the first Ada compiler to simulate a multiprocessor environment on a single processor Unix system. More than 4,000 modules in the compiler have passed ACVC1.10 verification as specified by the Department of Defense (DOD) in 1989.

CAS has moved all the Unix SVR3.1 source code from an ATT 3B2 to a Vax 11/750 by cross compilation and reverse engineering. They have also moved the top layers of this system to a 386/Xenix. CAS claims that this is the first domestic (Chinese) movement of a full Unix system.

ROBOTS

- The CAS reports that in the early 1980s they proposed establishment of a robot demonstration project that began operation in 1989. The cost was 58M yuan plus $5.9M (U.S.) foreign exchange. This is now called the CAS Shenyang Robotics Engineering R&D Center and occupies 34,000 m^2 of building space. The plan is to use this as a base to produce robots and develop and manufacture more products. Many related projects spring from this one.

- A medium-size underwater robot (Recon-IV-300-SIA-02) is being sold to the United States. This is claimed to be an improvement on a prototype brought from the United States. Ninety percent of this robot's parts are of Chinese manufacture. The robot has audio, video, sonar, and two hands and can perform five or six functions. Closed-loop control of depth and direction of navigation is included, payload is 160 kg, and maximum speed is 3 knots.

- A lightweight underwater robot (Gold Fish) also made in China is used in oil drilling, sea rescue, dam inspection, and repair.

- Nankai and Tianjin Universities have jointly developed a robot with vision, hearing, and touch capability (NKRC-03) can automatically control the amount of force when it grabs an object. This is claimed to be at the 1980s level world-wide and state of the art in China. This robot uses the NKV robot language to allow high level language programming; it is a standard second generation robot.

FACTORY AUTOMATION

The China Huajiing Electronics group claims that after a 2-year effort by more than 100 scientists they have developed China's first independently designed integrated-circuit computer-aided manufacturing (CAM) system, consisting of 11 subsystems (planning, production, management, process technique, quality control, economics, operations, materials, plate making, statistics, and system management).

The Beijing Institute of Machine Tools has built a physical simulation system for studying the various software parts of a flexible manufacturing system based on linear rail guided carts. The system can simulate transport, loading/unloading, control, and specific aspects of a machining operation.

The above suggests that there are a great many projects in the area of manufacturing. Most of these are related to automation and associated machine tools and numerical control equipment.

For example, last year the Second Chinese Machine Tool and Instruments Exposition was held in Beijing, and various newly developed machine tools, numerical control systems, sensors, computer-aided design (CAD) software systems, etc. were on display (226 metal cutting machines, 67 lathes, 37 grinders, turning centers, etc). There are, in fact, over 2,000 machine tool products manufactured in China, mostly for domestic use. However, the Chinese machine-too building industry is also trying to design products that will be marketable internationally (some have been already) and have identified several products that they claim are of world class, for example, a six-axis, four-link hobbing machine computer numerical control system that can be used for machining ellipsoidal gears. Another example is a unit for machining small diameter holes that is claimed to be twice as fast and equal in other specifications to a Raycon (U.S.) product. There are also cooperative agreements with major international companies such as Fanuc-Bese, GE, Werner-Kolb, and Schiess (German). It is not necessary to be an expert in this area to appreciate the main thrust, that the Chinese want not only to become self-sufficient but also to become net exporters of this technology.

OPTOELECTRONICS

- 140-Mbit/s hybrid optical terminal and 622-Mbit/s hybrid integrated-component module and distributed feedback laser diode.
- 1.5-micron, single-mode, narrow-linewidth, tunable semiconductor laser; semiconductor travelling-wave optical amplifier; Er-doped glass fiber amplifier; lithium-niobate optical-waveguide high speed modulator; 1.1- to 1.6-micron avalanche photodiode detector; and duplex frequency-division-multiplexing coherent optical communications devices.
- Various quantum-well optoelectronic devices.
- Optoelectronic integrated circuits made domestically.
- Superlattice growth of II-VI semiconductors and fabrication of optically bistable devices, bismuth-silicate spatial light modulator, molecular beam epitaxy growth of GaAs, and fabrication of GaAs/Si LEDs and MESFETs.

THE SECOND INTERNATIONAL CONFERENCE ON NUMERICAL OPTIMIZATION AND ITS APPLICATIONS

This article summarizes the Second International Conference on Numerical Optimization and Its Applications, held from 24-27 June 1991 at Xi'an Jiaotong University, Xi'an, China. Visits to the computing center at the Chinese Academy of Sciences (Beijing) and to Fudan University (Shanghai) are also described.

by David K. Kahaner and Stephen G. Nash

INTRODUCTION

The authors attended the Second International Conference on Numerical Optimization and Its Applications, Xi'an Jiaotong University, Xi'an, China, 24-27 June 1991, where Nash gave a contributed paper. Kahaner and Nash gave lectures at Fudan University in Shanghai. Kahaner lectured at the computing center at the Chinese Academy of Sciences in Beijing. These visits are described below.

BACKGROUND ON XI'AN

This was the second in a proposed series of conferences on optimization. The first was held in 1986, also at Xi'an Jiaotong University. The host was

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The entire staff of the institute, especially Dr. Chengxian Xu, worked extraordinarily hard to satisfy the requirements of the Western attendees and their families.

Xi'an Jiaotong University is one of about half a dozen in China (and one in Taiwan) with the name Jiaotong (meaning "transportation," or "commerce"). The first was founded in Shanghai in 1896, and the Xi'an campus was opened in 1956. It is a university with the main focus on natural science and engineering and secondarily on liberal arts and management. Student enrollment in Xi'an is about 12,000 including 2,200 graduate students. There are over 2,400 faculty including more than 750 at professor or associate professor level. About 250 foreign students are on campus from Canada, France, Germany, Japan, the Netherlands, Poland, Switzerland, the United Kingdom, the United States, and Hong Kong. Plans are to increase enrollment to 15,000 in the next few years with a corresponding staff increase.

Its campus was heavily treed, spacious, and attractive. There were a number of lovely gardens and fountains, and it was generally an enjoyable place to stroll. University buildings appeared to vary from brand new to 1950s vintage, and all seemed in good condition as far as we could tell. One Western attendee elected to stay at the university guest house, while the others chose an international hotel a short distance away. The guest house appeared to be perfectly satisfactory but lacked the ambience of the hotel.

(We should mention in passing for those who have not been to China that first class accommodations were available every place we visited. Western hotels such as the Hyatt, Holiday Inn, and the Sheraton are common and provide a level of service--and price--essentially equivalent to that in other countries. Of course, less expensive hotels are also widely available. But there is a discontinuity between the luxury in these hotels and the facilities used by working Chinese; this was very noticeable in Xi'an. Also, international hotels use a special currency that can only be obtained when visitors exchange foreign currency, and hence is not normally available to Chinese. Nevertheless, all the visitors to this conference were impressed with the fact that people on the streets looked, if not prosperous, at least well clothed and fed. In fact, one returning visitor remarked at how much improvement there had been since his last visit.)

Although we walked around the campus, there was no opportunity for a real tour. This was disappointing, as the campus literature lists a 1.4M volume library with 8K journals; several university-owned factories (machine manufacturing, electronic devices, computer manufacturing, research and teaching facilities); 62 laboratories (including structural strength and vibration, metallic strength and vibration, image processing, two-phase flow, lubrication and bearing, computer systems and applications, natural dielectrics, etc.); engineering departments (mechanical, energy and power, power machinery, electrical, information and control, computer science/engineering, materials science, chemical); as well as physics, engineering mechanics, architecture/structural engineering, mathematics, mechanology (machine design and manufacture), social sciences, etc. We were told that Xi'an has academic exchange agreements with almost 30 other universities including 10 in the United States and 6 in the United Kingdom, but we had no opportunity to meet any visiting scholars. The city of Xi'an has recently become internationally famous because of the discovery, in 1974, of many thousands of ancient, life-sized, terra-cotta warriors. This site and the enormous activity surrounding it are really wonders of the world. Visiting conference attendees always want to see these, and conference organizers now build such a trip into the schedule. We feel that it would also be useful to allow time within the scientific program for a careful university tour, and in fact there appeared to be ample slack time within the program for this.

There is a serious language problem confronting Chinese scientists who wish to communicate in English. The Western attendees all agreed that many potentially interesting talks were almost impossible to follow, although it was clear that the Chinese speakers had prepared carefully. In fact, many scientists actually read their papers and yet some of these were among the most difficult to understand. The printed papers that were available to us were acceptable, but a large fraction would still be rejected for publication in critical journals. In a perfect world we would hope that Western scholars would be willing to go halfway and learn a little Chinese, but in reality the language of science--especially computation--is English and the Chinese need to continue working to improve their skills. The Western attendees also felt that, language issues aside, the Chinese need to spend more time training their younger scientists on the mechanics of lecturing, especially with transparencies. We often forget that presentation skills that are taken for granted in the West need to be learned somewhere. The university has a department of foreign languages and has specialized courses in English (and Japanese) for science and technology, but perhaps science students do not have much opportunity to participate in these. Perhaps senior Chinese scientists could coach their younger colleagues. Also, in the West we have many excellent and experienced speakers, and we suggest, respectfully, that a few simple lectures on "how to give a lecture to a Western audience" presented by well known Western scientists during their visits to China would be very helpful in improving information flow between the countries. (Needless to say there are many Western scholars who could also profit by attending such lectures.)

The lectures were held in a building that was nearly new, in one medium sized lecture room and two small classrooms. The latter had rather poor overhead projectors. This caused a real problem, as the combination of badly focusing equipment and extremely flimsy transparencies made a number of the Chinese talks even more difficult to follow. Actually, transparencies are very expensive and it is not surprising that they are used economically, but perhaps it would have been better to shave the budget in some other areas instead. Surprisingly, the building also had a spectacular lecture hall that would have been perfect, but for some reason was not used.

TOPIC OF THE CONFERENCE

Numerical optimization has many applications throughout the applied sciences, as well as in numerous business and military applications. It has been an especially active research area in recent years because of the success of interior point methods in linear programming. This conference aimed to "further these developments by bringing together the chief numerical analysts, applied mathematicians, operations researchers, computer scientists, and engineers with interests in numerical optimization and its applications from around the world to share their work."

In the preliminary program it was announced that there would be five invited talks (two from the People's Republic of China, one from Taiwan, one from Germany, and one from Canada) as well as 93 contributed papers (most from China). There were a substantial number of changes to the final program regarding the contributed papers. Revised schedules were produced each morning, but even so, there were gaps in the program due to last minute withdrawals, absences, or "no-shows" (by both foreign and Chinese speakers). Foreigners at the conference included one from Taiwan, one from Germany, one from New Zealand, one from Spain, four from Italy, one from Canada, and four from the United

States. Among those who were absent were scientists from the Soviet Union, Iran, and Vietnam. The conference was run in English, corresponding to its designation as an international meeting. Cash prizes were awarded for the best three papers by young Chinese researchers, although the third prize was split between two papers. Prizes were decided by a committee consisting of three Chinese, plus L.R. Foulds (New Zealand), W.J. Gilbert (Canada), and chaired by G. Alefeld (Germany). Prizes were as follows.

First prize: Huang Zhijan, "On the Convergence of the Brent Method" (joint work with Wang Deren)

Second prize: Wei Bin, "A Class of Reduced Gradient Methods for Nonlinear Programming Problems With Linear Constraints" (joint work with Xu Chengxia)

Third prize: (split) Xu Xiaojie, "On the Implementation of Interior-Point Methods for Linear Programming"; Xu Chen, "Modelling of Flexible Robot Dynamics With Optimal Shape Functions"

Because the contributed papers were sometimes presented in three parallel sessions, we were not able to hear all the talks at the meeting. The information below is based on the talks that we attended, and the general comments (both those earlier and just below) seemed to be shared by all the Western attendees.

Many of the talks were outside the mainstream of optimization algorithms and applications as viewed from the West. The algorithmic topics often seemed old fashioned and the applications topics esoteric by Western academic standards. There are a number of possible explanations.

(1) The references in the papers were often to years-old papers in Western journals, perhaps indicating a difficulty of obtaining journals (although, see the discussion of Fudan University below).

(2) The algorithmic research in China is severely constricted by the lack of computing equipment. Some universities have virtually no equipment, while others only have a limited number of small machines (such as IBM PCs, XTs, and ATs, and their equivalents). There was evidence that a small number universities had parallel computers including at least a few Western machines, such as ELXSI (now defunct), but none of the papers that we heard at the conference, nor any of the individuals we spoke to, made use of these machines. Thus, there is a natural tendency to "make-do" and adjust techniques and problems to those that can be handled on small machines, or perhaps just pencil and paper. Not surprisingly, there is a great deal of theoretical research and analysis and much less emphasis on experimental computation.

(3) The applications that were described were frequently connected with Chinese manufacturing, transportation, or distribution problems and, as with computing equipment, in China many of these are not as sophisticated as in the West; this sometimes led to what seemed to be unusual assumptions in the models that were being used. Although we have seen a large amount of very excellent theoretical research from Chinese scholars, a heavy emphasis in the Chinese papers presented at this conference was on very direct and practical applications, optimization of helicopter rotor blade design, electrical power loading, shape of bellows, and river pollution control. This is related to the focus in Chinese research on using technology to solve the many serious problems confronting the country. In the West, academic researchers tend to be much more interested in developing new techniques than in applying existing ones (even if very creatively) to specific problems.

There was an intense curiosity among the Chinese researchers about work in the West. Many of the talks demonstrated that these researchers have considerable technical and analytic skills but lack library and computing resources to support these skills, or at least that communication between the research staff and these resources is weak and needs to be strengthened.

CONFERENCE PRESENTATIONS

What follows are notes on some of the talks that we attended. Not all talks are mentioned since in many cases the abstracts in the conference program provide adequate descriptions of the content of the talks. Speakers are from China unless otherwise noted.

- Goetz Alefeld (Germany)--Recent results for the interval-arithmetic version of Newton's method. An analysis of the divergence (failure) of Newton's method when interval arithmetic is used.

- Shen Zuhe--Interval-majorant method for global optimization and its applications. A review of various theoretical results and algorithms for global optimization was given. These were extended to the setting of interval arithmetic and the results were applied to a mini-max problem.

- Massimo Gastaldi and Agostino la Bella (Italy)--Optimal growth in a multiregional and multisectoral economy. An attempt to reduce regional disparities in the Italian economy through optimization methods and models. They presented a multiregional and multisectoral dynamic model. There were deficiencies in the pure model (e.g., lack of data), and optimal control techniques were used to remedy these deficiencies. Solutions were then obtained by dynamic programming, using discretization in the time variable.

- Sergio Barba-Romero (Spain)--Nonlinear optimization models for the new Spanish Autonomous Communities financing system. Starting with a basic linear programming model, quadratic constraints and objective terms were added, with the possibility of additional cubic constraints if the original augmented model was inadequate. The problems were solved using GINO on a microprocessor (the problems had 37 variables and 32 constraints).

- Li Naicheng and Zhang Kecun--Parameter optimization method for problems of elastic fluids. Solving lubrication problems via nonlinear parametric programming, based on an ordinary differential equation (ODE) boundary value problem. A guess is made for a pressure curve p(x) (a parametric model), and then a least-squares objective function is used to get a solution. In this talk p(x) was a spline. Numerical solutions were obtained.

- Li Yiping--Cubic potential for strictly nonlinear oscillators. A series expansion was used to cope with two different time scales in the problem. An analytic solution was obtained for the case of a cubic potential, and the author considered cubic approximations to more complex potentials.

- Li Pingyuan, Pan Xiaoqin, and Ding Peyong--On the corresponding points of contact, line of contact, and velocity ratio of two quadratic arcs that are best approximations in involute profiles. This talk was concerned with the manufacture of gears. Various assumptions and restrictions were imposed, apparently because of the limitations of Chinese gear-manufacturing equipment.

- Feng Chengmin (Taiwan)--Multiobjective optimization, theory, and application. This was a survey of basic ideas in this area. There were several other papers on multiobjective optimization presented at this conference. The topic is of considerable interest in China, and there will be a conference in Taipei, Taiwan (Tenth International Conference on Multiple Criteria Decision Making), 19-24 July 1992, at National Chiao Tung University, 4F 114 Sec 1, Chung-Hsiao W. Rd., Taipei 100 Taiwan, Republic of China.

- W.J. Gilbert (Canada)--Newton's iteration method and its generalization. The speaker looked at generalizations of Newton's method for solving f(x)=0. The generalizations included (a) variants for multiple roots, (b) higher order methods, (c) the secant method, and (d) Steffenson's method. Julia sets associated with the convergence of these methods were illustrated for various polynomial examples in one variable.

- S.S. Oren (U.S.)--Optimal pricing of delivery priority and spec levels for semiconductor products. The speaker developed a model for setting prices of custom VLSI chips. The formulation was a nonlinear programming problem. The model was based on the fact that chips are not uniform (they vary in speed, for example), but this cannot be determined until after manufacture.

- Dorit Hochbaum (U.S.)--The empirical performance of a polynomial algorithm for constrained nonlinear optimization. The speaker considered a nonlinear programming problem with a separable, convex objective function and linear inequality constraints. Some complexity results were derived based on a discretization of the variables in a bounded interval.

- Yue Ming--Cone duality theorem of semi-infinite programming problem and relative algorithm. The speaker considered a semi-infinite linear programming problem, where all the points must lie in a closed convex cone. The dual problem was derived. Under strong assumptions, some further results were derived in the nonlinear case.

- Stephen G. Nash and Ariela Sofer (U.S.)--A general purpose parallel algorithm for unconstrained optimization.

- Gao Li--An algorithm for one-sided Huber optimization with applications to circuit design centering. Huber optimization is a combination of L-1 and L-2 optimization which seems particularly useful in those cases where the sign of the error at the data values is important. The basic algorithm also switches between a trust-region Gauss Newton method and a Quasi-Newton method.

- Wang Shiding--Research on optimal long term scheduling of an irrigation-electric power reservoir. There are over 85,000 reservoirs in

China. Using an lp model the author claims to have been able to increase total electrical output 4%-5% along one particular river.

- Tian Fengwei--A new algorithm for optimal streamflow regulation of cascade hydro reservoir systems. A combination of well known methods, but the application was claimed to improve output about 7% along one river.

- Tian Zhiyuan--Convergence of simplex method for two-variable functions. This title refers to the Nelder-Mead direct search method for unconstrained nonlinear minimization. Convergence was established for certain two-variable problems.

- Yang Boting--The software package of optimum design for valve gear mechanism of internal combustion engines. This paper describes a software package for Cyber machines, of more than 10,000 lines of Fortran-77. The speaker presented many numerical results indicating that the software accurately models this complex system. It was very difficult to determine the actual optimization methods that were in use, but if the results are valid this package might be of practical interest in the automotive industry.

- Hu Xinsheng--Complementarity problem of set functions and its application in nondifferentiable optimization. Some theoretical results on set-valued functions. The results were applied to nonsmooth optimization problems, with computational results on an IBM PC.

- F. Facchinei and S. Lucidi (Italy)--On the solution of simple constrained optimization problems by an exact penalty approach. The authors considered the problem of minimizing a nonlinear function subject to either (a) bounds constraints or (b) nonnegativity constraints plus the restriction that the variables sum to unity. This was solved via an augmented Lagrangian approach (i.e., using a differentiable exact penalty function).

- Fu Li--The approximating exact penalty function method. An exact penalty function was derived using general norms for the penalty terms.

- Pen Benchen--The application of optimum method in wing structure D-design of airplane. This was a very brief introduction to a software system (over 70K lines) developed since the late 1970s.

- Guo Dinghe and Zhang Kecun--Numerical method for conditional variational problem with double objectives. This talk was concerned with the design of a lens. Two objective terms were used to control spherical and chromatic aberration. The problem was solved via parametric programming.

FINAL COMMENT

Meetings such as this, held in far away and exotic places, have a special fascination to Westerners. But with language, culture, climate, and time differences, participating in them is plain hard work, and sometimes the scientific rewards are not obvious at first. Nevertheless, visiting attendees are important to their hosts and hence have a significant responsibility to them and to their scientific peers. This responsibility is best discharged by active participation and attendance. Prof. Goetz Alefeld (Germany) deserves special commendation; he was in constant attendance and provided almost nonstop encouragement and suggestions to younger Chinese scientists. We also think that U.S. funding agencies should ask for full accounting from Western attendees, intellectual as well as financial.

FUDAN UNIVERSITY, SHANGHAI

On 3 July we visited Fudan University in Shanghai. Our host was

Prof. Erxiong Jiang
Chairman and Prof. of Department of Mathematics
Fudan University, Shanghai
PRC
Tel: 5491427
Fax: 5453039

although he was not at Fudan on the day of our visit (Kahaner met Prof. Jiang the day before in Beijing at the Academy of Science). Instead, we were escorted by Prof. Cao Zhi-Hao, also in the mathematics department at Fudan.

Shanghai is said to be the industrial heart of China, comparable to Chicago in the United States. It was certainly highly industrialized and crowded. Our visit coincided with several weeks of heavy rains and the resulting serious flooding, so most of our movements were restricted.

We had both been asked to give lectures, and then were shown around the university. This was between sessions, and the campus had the typical look associated with that period everywhere in the world. Our original plan was to spend the afternoon and evening with university staff, but weather problems curtailed this, and we had much less interaction than we would have liked. The lectures were primarily attended by about 15-20 students, who characteristically had very few questions. There was also a serious language problem. By now, Kahaner has a reasonable amount of experience giving lectures in English to nonnative speakers, but he felt that a large fraction of the lecture content was lost. And generally, he believes that the level of English knowledge in China is much lower than in Japan, even among relatively well traveled senior scientists. In fact, we were told that senior (hence older) scientists are more likely to be comfortable speaking Russian than English.

A short campus tour included the Mathematics Library and the Computing Center. The library had an extensive collection of journals and books, both Chinese and foreign. Although some of the foreign journals were originals, most were reproductions including copies of SIAM, ACM, IEEE, Elsevier, and others. We were told that there is insufficient funding to purchase these journals for all the universities at international foreign exchange rates. Instead, one subscription is purchased by the Chinese Government, and this is then used for widespread copying. At the time we examined library shelves (July 1991), these copied journals were well stocked through the end of 1990. We were also told that some original journal issues were provided by professors who are on journal editorial boards and receive free subscriptions. The collection of foreign books, however, appeared to consist exclusively of originals. There was evidence that many new books were entering the library, consisting of typical research monographs that one would expect in such a library, but also some more unusual titles (*Statistics for Lawyers*) that are surprising given the stated tight budgets.

We were interested in the issue of journals because it related directly to intellectual property rights (IPR) and also to every scientist's desire for full and free flow of information. There are various perspectives on protection of intellectual property, with some claiming that socialist enterprises shouldn't adopt patents, or that patent laws would mostly benefit foreigners because there are fewer inventions in China. These worries have proved unnecessary and China is striving to improve IPR. However, there are several departments charged with patent, trademark, and copyright protection in China, and this slows down any changes. Even with new laws concerning IPR, violation of property rights is still common. Tang Zongshun, consultant to the State Council and vice-chairman of the China branch of the International Association for Intellectual Property Protection, feels the key question is how to enforce and coordinate existing laws effectively.

We asked two ex-presidents of SIAM their opinions on journal copying. Here are their personal opinions. Prof. Gene Golub (Stanford):

> The problem of exchanging journals with third-world countries has plagued us for some time. I don't know what to do at this time, but we shouldn't be passive and do nothing. The only thing I can think of is to publish some international journals and then use the profits for sending journals. Does the American Mathematical Society have any policy? Here's a place where the mathematical societies might cooperate. I think there's a real need to begin to communicate with third-world organizations. Perhaps this can only be done through governmental channels.

Dr. Bill Gear (formerly University of Illinois, now NEC):

> At the moment individuals in countries with the economic situation of China cannot afford to subscribe to journals such as those of SIAM, even if we reduced the costs to the point we were losing money on each copy. Unless the membership expressed a strong interest in proving significant economic support to scientists in other countries, it seems to me that the officers' fiduciary responsibilities to members do not permit them to subsidize particular groups in a major way. On the other hand, I suspect that most members would want to be as helpful as possible to individual scientists and give them access to international scientific publications. Thus, while a country is in a state such that there is no prospect for its scientists to get journals any other way, I personally would not want to see pressure mounted to stop the process of reproducing journals internally for distribution to libraries. I imagine that the PRC Government can produce copies far less expensively than we can in the U.S. However, I would like to see agreements concerning such distribution. These should specify the extent to which distribution is permitted and some payment to offset the costs of production of the original. Any distribution outside of the country should be banned. Payments could be based on the economic situation in the country and be renegotiated from time to time.

Fudan University has a computing center, and we were taken on a tour by Prof. Chen Jing Hai, who is its director. He led us to understand that this resource is not made available to all departments of the university. Instead, it is associated with the Computer Science Department, and the Mathematics Department does not seem to have ready access to the equipment. The equipment includes dozens of personal computers (IBM PCs, XTs, and ATs, as well as the Chinese Great Wall equivalents), an older Honeywell mainframe, a Hewlett-Packard minicomputer, as well as terminals, tape and disk drives, and printers. There were one or two Unix workstations. We were not shown any examples of the projects in progress at the university. Also, the center was not in wide use the day we visited, but this could be because it was summer and classes were not in session.

COMPUTING CENTER, ACADEMY OF SCIENCE

Kahaner visited here on 2 July. His host was

Prof. Zhong-ci Shi
Prof. of Mathematics and Director of the Computing Center
Academia Sinica
P.O. Box 2719
Beijing, PRC
Tel: +86-1-283967 (office)
+86-1-2562192 (home)
Fax: +86-1-2562485
Email: bmaacc@ica.beijing.canet.cn

Prof. Shi is also the vice-president of the Chinese Mathematical Society and the head of the National Laboratory of Scientific and Engineering Computing. He and Kahaner met at an international conference in Japan in 1990. Shi is well known for his work on analysis of finite element methods for partial differential equations, although this is highly theoretical. He has traveled widely, and in fact was leaving soon after for a SIAM meeting in Washington, DC. He is also responsible for general purpose computing at the Chinese Academy of Science (CAS), which is in reality a large collection of research institutes. Shi told me that there are about 80,000 students and researchers in and around Beijing at institutes and universities.

The CAS computer center is about 25 years old, and not only encompasses the computers but also almost 500 staff, including more than 300 researchers and technicians of which about 100 are equivalent to either full or associate professor level. Thus the center not only provides computer service but also performs teaching and research in computational mathematics, applications, computer science, networking, Chinese character processing, etc. In addition, it is also responsible for the establishment of a scientific database system, which is considered a national key project. This involves work on about 20 scientific databases in chemistry, physics, biology, geography, etc., which will eventually be implemented on a large distributed system. About 15 master's and 10 Ph.D. students are admitted each year, and there are also a few post-doctoral students.

Hardware at the center is currently based on two IBM mainframes, a 4341 and 4361. Prof. Shi explained to me that the actual computer center was shut down because various rooms were being moved, and about the only computer related material Kahaner saw was a large stack of floor panels. But several Convex C120 systems have recently been sold to China, so it is a good bet that one of them will be installed here.

Shi explained that there are a number of major research projects, oriented around

- Mathematical physics (Hamiltonian systems--see below, fluid mechanics, quantum chemistry, structural analysis, seismic exploration)
- Numerical solution of partial differential equations (finite element, variational, multigrid, and boundary element methods)
- Software for science, engineering, and statistics
- Optimization (interior point and trust region methods)
- Inverse problems
- Computational geometry
- Computer algebra for cryptography
- Chinese character I/O
- Parallel algorithms
- Fourth generation computer languages

as well as some unusual projects such as Lie algebras and numerical methods for pharmacology. There are also several journals including the *Journal of Computational Mathematics* (in English) and an English translation of the *Chinese Journal of Numerical Mathematics and Applications*.

Kahaner was particularly interested in available scientific software. The center subscribes to IMSL (U.S.) and NAG (U.K.) and also has its own library in mathematics (STYR), statistics (SASD), and computational physics (CPS). For example, STYR, which is the responsibility of Cui Fun-Zhi (Tel: 256-3753) at the same address as Shi, has over 300 user callable modules (almost 700 modules total) written in Fortran-77 and made available on PCs under DOS, Unix, and OS/2 as well as the center's mainframes in the following categories.

- Special functions
- Fast Fourier transform (FFT)
- Splines
- Quadrature (one dimensional and multiple)
- Eigenvalues and eigenvectors
- Nonlinear equations
- Least squares
- Roots
- Linear and nonlinear programming

- Optimization (constrained and unconstrained)
- Ordinary differential equations
- Matrix and vector computation
- Graphics, including surfaces
- Machine parameters and error handling

Thus, it looks to be functionally similar to large software collections in the West, such as the SLATEC library, which is used at the major Department of Energy (DOE) laboratories and other places. Kahaner was told that several Japanese scientists collaborated on this work, and it has some relationship to the NUMPAC project from Nagoya and Chubu Universities.

Also at the Academy was

Prof. Kang Feng
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Beijing, PRC
Tel: +86-1-289001 (office)
+86-1-285203 (home)

Prof. Feng is also an ex-president, Chinese Society of Computational Mathematics. Since the early 1960s he has been interested in Hamiltonian dynamics. By that we mean the description of the motion of an n-degree of freedom system by use of the 2n ordinary differential equations describing the first partials of the system's Hamiltonian. The geometrization of these ideas, developed by Poincare, has been named "symplectic geometry." Virtually all real physical systems with negligible dissipation can be cast, somehow, into Hamiltonian form, and Feng and his collaborators are convinced that this is a fruitful starting point for development of numerical methods. They have a substantial collection of papers (in English) describing the ideas and a few in which symplectic Runge-Kutta and leap-frog schemes are used to integrate the nonlinear oscillator and even more difficult systems, with excellent results over long-times. Feng's first papers on symplectic difference schemes appeared in 1984. Kahaner was not aware of this work before. It is really excellent and deserves to be much better known in the West. One accessible reference is the following: Feng Kang and Qin Meng-shzo, "Hamiltonian algorithms for Hamiltonian systems and a comparative numerical study," in *Computer Physics Communications* 65, 173-187 (1991).

Feng was also very interested in Japanese research on parallel computing. Kahaner was not made aware of any Chinese work on parallel computation, except of a very theoretical nature, and feels that this mostly stems from lack of access to suitable platforms. Chinese scientists are aware that they are far behind in this area and that there is a substantial "spin-up cost" that they will eventually have to pay. The few Chinese parallel processing projects we read about are either based on transputer systems that researchers are configuring themselves or on old ELXSI hardware. Lack of electronic networks prevents remotely based researchers from accessing even these systems.

One of the most interesting aspects of this part of the visit was the fact that some Chinese institutions ARE beginning to have electronic mail. This is still in a very undeveloped state compared to Western countries, but as all of us who use this kind of communication know, it is an essential ingredient in timely information flow. For many it would be difficult to imagine life without Email.

Stephen G. Nash is an associate professor in the Operations Research and Applied Statistics Department at George Mason University. He graduated in June 1982 from Stanford University with a Ph.D. in computer science; he obtained his B.Sc. degree in mathematics from the University of Alberta in May 1977. Before joining George Mason University, he was an assistant professor in the Mathematical Sciences Department at The John Hopkins University. Prof. Nash's research interests are in numerical analysis, particularly linear algebra and function minimization. His book, *Numerical Methods and Software* (coauthored by David Kahaner and Cleve Moler), was published in the fall of 1988. A second book, *A History of Scientific Computing*, appeared in 1990.

ARTIFICIAL INTELLIGENCE BASED MEASUREMENT AND CONTROL

A summary of the Eighth International Symposium on Artificial Intelligence Based Measurement and Control (AIMaC'91), 12-16 September 1991, Kyoto, Japan, is given.

by David K. Kahaner

INTRODUCTION

The Eighth International Symposium on Artificial Intelligence Based Measurement and Control (AIMaC'91) is a spin-off meeting. Earlier in September (5-10 September), the International Measurement Confederation (IMEKO) held a large World Congress XII in Beijing. A special interest group, the Technical Committee on Measurement Theory (TC7), sponsored AIMaC'91. Locally, the meeting was organized (and held at Ritsumeikan University in Kyoto) by the Society of Instrument and Control Engineers of Japan (SICE), a body with 9,000 plus members. This was the eighth AIMaC symposium; the earlier meetings give a fair sense of the center of gravity of the membership.

Year	Location
1969	Czechoslovakia
1971	Hungary
1973	East Germany
1975	The Netherlands
1976	United Kingdom
1978	U.S.S.R.
1979	U.S.S.R.
1981	Yugoslavia
1982	East Germany
1984	Italy
1986	West Germany
1987	Hungary
1990	West Germany

Thus, until this year, the activities of TC7 were essentially all European. The TC7 committee that plans these meetings is composed of about 20 scientists from 18 countries including the United States. This year's meeting saw about 150 scientists from 21 countries come together in Kyoto, Japan, to listen to 6 plenary lectures, 10 invited papers, and more than 75 submitted papers. (About half the participants were local, Japanese.) There was also a very small vendor exhibit, with about a dozen displays showing a variety of test equipment and a fuzzy hardware system for the appraisal of orthodontic results from Rohm. Other than myself, I was only able to locate one other U.S. participant. The main topic of the current symposium was intelligent measurement, i.e., using the computational power of today's smart chips to develop "intelligent sensors" and to utilize AI techniques in modeling, design, management, operation, diagnosis, etc. Further details about this symposium, as well as forthcoming ones, can be obtained from

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AIMaC'91 Executive Committee
Faculty of Science and Engineering
Ritsumeikan University
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Kita-ku, Kyoto 603, Japan
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Fax: +81-75-465-1209

LOCATION OF THE SYMPOSIUM

The symposium was held at Ritsumeikan University, a private university in the northeast part of Kyoto, within walking distance of many famous sites. Ritsumeikan was established in 1895, but only in the past few years has it begun to establish itself with graduate programs. Even so, it still has only a few hundred graduate students, although it has more than 20,000 undergraduates as well as a few thousand who go at night. Over the years, Ritsumeikan has awarded almost 150,000 bachelor's degrees, 1,800 master's degrees, and 160 Ph.D degrees. It now has active graduate programs in business administration, arts and philosophy, and various aspects of international studies. Graduate programs in science and engineering are in place and growing. (Incidentally, it has recently been projected that by the year 2005, Japan will be lacking 480,000 scientists and engineers--300,000 in engineering, 130,000 in science, and 40,000 in medical science/pharmacy, while it will have a 33,000 person oversupply of liberal arts graduates.) Ritsumeikan has a 1.4 million volume library and a special depository of United Nations associated volumes, numbering about 40,000 plus documents. For me, one of the interesting aspects of the university is the degree to which it has become international; there are exchange agreements with over a dozen large universities in the United States, Canada, the United Kingdom, France, Germany, Poland, the U.S.S.R., China, and Australia. Most of this is new; there are only about 300 non-Japanese students, mostly from Taiwan, Korea, China, and Malaysia. But in September 1991 about 100 Ritsumeikan students will spend an academic year at the University of British Columbia, Canada. The campus is attractive, with some (not all) new buildings (including the one in which the symposium was held). Although at the moment there are very few Western students, those looking for a Japanese experience should consider it. For additional information, contact

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Kita-ku, Kyoto 603, Japan
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COMMENTS

"Sensible" Sensors

The distinction between sensors and computers is narrowing, and in some situations it might have already disappeared. Several perfect examples of this were given by

Shoei Kataoka
VP Research
Sharp Corp.
Corporate R&D Group
273-1 Kashiwa
Kashiwa-shi, Chiba 277, Japan

who gave one of the plenary lectures and described two of his company's research projects. (Kataoka also commented that part of the research was funded by a recently ended 10-year Ministry of International Trade and Industry (MITI) project, Fundamental Technology for the Next Generation, and that the type of research and results proved that "it was untrue that Japanese research is only in applied R&D areas.")

Kataoka focused on what he termed "sensible" sensors. These are devices that combine physical sensors; actuators that incorporate feedback from/to the sensors; and a module that allows deduction, learning, and abstraction. Such a sensor is linked to a large knowledge database and also to a human (perhaps remotely). Kataoka hopes that this type of sensor could be used to detect such things as emotion by examining a real time image of a person and extracting information about tension, anger, joy, age, etc. Of course, we are not at that stage yet, but the sensors Kataoka showed illustrated how far we have come from the days of analog voltmeters.

Three-Dimensional (3D) Image Sensor on a Chip. Kataoka made a very simple point that, without dismissing the unsolved technical problems, two-dimensional (2D) integrated circuits (ICs) are bound to be less efficient than three-dimensional ones by showing photographs of two Sharp facilities, one a sprawling factory in Tennessee and another an office building in Tokyo; the latter has shorter paths, has a higher packing density, is multifunction, etc. Sharp is now working on its second prototype of a four-layer, 14.3-mm^2 chip fabricated by silicon on insulator (SOI) technology, with about 280K devices. The top layer (fourth) has 55,000 photo diodes and acts as an imager, i.e., an optical-to-electronic conversion (what used to be the "sensors") of 420 pixels per character. This represents a 10x14 bit character matrix. Signals are passed in parallel to the third layer that digitizes, using majority decision, and then passes the data (also in parallel) to the second layer, which acts as a data mask. The bottom (first) layer is an associative memory. If an input image is thought to match one of the stored images, then the latter image is output. The individual layers are zone melted polysilicon (into a single crystal), although the circuit design on the chip is basically made according to the design method used for conventional 2D ICs. Kataoka is hoping that a real 3D architecture will be designed in the future. Nevertheless, the chip works, as we were shown several examples of input and output characters. (In the context of this discussion it is not appropriate to put too much emphasis on the algorithmic details.) Is this a sensor or a computer?

Intelligent Optical Odor Sensor. This is also an ongoing project and is being supported as part of MITI's program in bio-electronics. Odor (smell sense) has been one of the most difficult sensors to realize. Partly this is because such a sensor must be exceptionally sensitive and partly because smell is a combination of various kinds of molecules. The human olfactory system can detect very low levels of odors and also distinguish different odors present in mixtures. The human system consists of several million receptor cells and olfactory bulbs. The receptor cells sense odors and their signals are transmitted to olfactory bulbs where signals are parallel processed and some profile of the signal is used to distinguish odors. Sharp's approach to such a sensor uses photo-sensitive organic films. (These films change color or intensity on contact with different molecules.) The receptor plate consists of a two-dimensional array of various dye films (the dyes used are solvatochromic dyes and color formers). Output of the plate goes to a photochromic film that acts like an optical storage. Finally, output goes to a third layer, of thresholding film, acting like an optical processor. The films were prepared on glass by spin coating from tetrahydrofuran or other solutions containing dye and a polymer. In the example, Kataoka showed that various gases could be distinguished (methanol, acetone, isoamyl acetate, acetonitrile, ethanol, ammonia, and others). At the moment this is a pure optical device, i.e., non-digital. But Sharp is now experimenting with attaching the output to a neural network to enhance its decision making ability. Is this a sensor or a computer?

Scope of the Papers

As might be expected at a conference such as this one, the technical range of the talks was very wide. There were several very high level papers. One of the best examples of these was given by

Ludwik Finkelstein
Measurement and Instrumentation Center
City University
London EC1V OHB,
United Kingdom

in which information, knowledge, measurement, perception, information machines, etc. were given precise definitions in the context of sensor and measurement applications.

Gerhard Barth
German Research Center for AI
Postfach 2090
D-6750 Kaiserslautern, Germany

gave a very readable and coherent survey explaining what is knowledge processing, what are neural networks, etc. (This was an excellent introduction, but the content was a bit disappointing based on his title "Knowledge Based Systems--State of the Art and Future Trends.") For me, though, the most interesting of these general talks, and the one that defined best the direction this field is heading, was by

Giuseppe Zingales
Electrical Engineering Dept
Via G. Gradenigo 6/A I-35131
University of Padua
Padova, Italy

on "The Role of Artificial Intelligence in Measurement." Zingales points out, among other things, that

> When the outcome of some procedure depends on the processing within a logical structure of physical quantities, attention should be paid to the real meaning of those measurements, that is, to their logical foundations. Any AI application needs to lay on a sound theoretical basis; providing the required support means that basic aspects in the science and practice of measurement have to be thoroughly understood, or, in some cases, even revised and reassessed.

His paper also includes a bibliography of several dozen items.

Valery Ivanor
All-Union Research Institute of Electrical Measuring Instruments
85, Prosveshenia Av
Leningrad, U.S.S.R.

and

Geniy Kavalerov
All-Union Scientific Technical Society of Instrument Industry
17, Marx Av
Moscow, U.S.S.R.

also gave a high level formalization of metrological aspects of information processing.

Another remarkable survey, although not related to AI, was "A Decade of Development of Electric Measurement in Theory and Applied Technology in China," by

Jiaoxian Ning
Institute of Mechanics
Chengdu University of Science and Technology
Chengdu 610065, Sichuan
People's Republic of China

Although this is far from my area of technical expertise, it is written in exceptionally clear English and has a 41-item bibliography. Another overview was given by

Dietrich Hofmann
Friedrich-Schiller University Jena
Lobdergraben 32
D(O)-6900 Jena, Germany

in the field of PC-based visualization techniques for in-plant quality control. It was very nicely done, with a useful list of unsolved problems, but not about AI.

Another excellent tutorial on "scalelogy," "nominal scale," and classification, such as what one ought to use to analyze IQ scores, was given by

Hiroshi Watanabe
Faculty of Engineering
Tokyo Institute of Technology
2-12-1, Oh-Okayama
Meguro-ku, Tokyo 152, Japan

This looks to be fertile ground for AI approaches, although the author only touched on these very briefly.

A large number of papers were applications, on topics that varied all over the place, from the computer-aided design/manufacturing (CAD/CAM) area, boiler operation, driving simulator, flow regulators, etc. Most of these paid very little attention to what computer scientists would call AI in the sense that a methodology was developed or applied that could be generalized and used later, although some authors did employ fairly well established methods such as case-based reasoning, model-based methods, fuzzy theory, system identification via spectral analysis, recursive estimation, auto regressive (AR) models, maximum likelihood, image processing, etc. Several of these papers were very interesting in their own right, such as one by

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and Systems Engineering
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Kita-ku, Kyoto 603, Japan

who has developed a fast extension to standard Hough transforms and applied this to extracting road edges from the visual field of a mobile robot. Road-edge determination was also a key aspect of a paper by

Yoshikuni Okawa
Faculty of Engineering
Osaka University
Yamadaoka, Suita, Osaka, Japan

in the (much more difficult) problem of reading signs painted on road surfaces. The one U.S. paper by

Chun Cho
Fisher Controls International
205 S. Center Street
Marshalltown, IA 50158

was about optimization of energy in industrial plants. This uses interesting optimization techniques but, as far as I can tell, no AI. There were a few good applications of expert systems, by now pretty well understood in the engineering community. For example,

Shin Tanabe
AI Engineering Section
Application Engineering Dept
Yokogawa Electric
Shinjuku Center Building (50F)
1-25-1, Nishi-Shinjuku-ku,
Tokyo 163, Japan

described a real time system that his company uses to run one of its power plants. Another paper with somewhat more generality was given by

David Vander
Ford Motor Company of Australia
Melbourne, Australia

describing a system to assist designers in selecting measuring instruments depending on the surface finish, flatness, dimensional accuracy required, etc. Biesen (Belgium) gave a good summary of PC-based expert systems designed to help experimentalists. To my surprise I had used two of these, Asyst and Asystant, and never realized that they were expert systems, thinking instead that they were only high level interactive environments (to be fair Biesen classified these as first-generation expert systems). Third-generation systems involve iconic programming and the use of virtual instruments, best typified by Lab View from National Instruments. The newest systems have large databases of instruments and also provide a feedback from/to the physical instrument.

Almost all of the "fuzzy" papers were about applications and were presented by Japanese or Chinese. (I have already mentioned in several reports that the Japanese and Chinese are very aggressively applying these techniques to applications.) An exception was by

Laurent Foulloy
Laboratoire d'Automatique et de
Micro-Informatique Industrielle
University of Savoie
B.P. 806
74016 Annecy Cedex, France

who gave an elegant description of sensors that compute and report linguistic assessments of their values, a step beyond today's smart sensors--Foulloy calls them symbolic sensors. This is basically theoretical work; a symbolic sensor is a general component that can be reconfigured to adapt itself to the measurement context. In the discussion after this paper Foulloy was asked "why fuzzy?" Declining to get into a long discussion, he observed that this was an easy way to implement a nonlinear controller. (The more theoretical types in the audience seemed unconvinced, but I thought this was an apt answer.) Another nonapplication paper was by

Francois Terrier
Dein/Sai Ce-Saclay
Fif/Yvette Cedex, F-91191 France

who discussed linguistic fuzziness.

Of the application papers about fuzzy logic, one worth mentioning was by

Toshio Fukuda
Dept of Mechanical Engineering
Nagoya University
Furo-cho
Chikusa-ku, Nagoya 464-01, Japan

who considered a system composed of multiple sensors (such as on a robot) and discussed the problem of how to integrate data from overlapping regions. His specific problem was using three distance sensors, each accurate over different (overlapping) ranges. His solution is to use both a neural net and fuzzy logic.

At the far end, a few papers were about algorithms and problems that would have been more appropriate at other conferences. But, I would characterize the greatest fraction of the papers as being about intelligent measuring techniques in the sense that some computing capability was integrated with sensors for very specific problems such as gravity flow, high precision temperature measurements, scanning tunneling microscopy, capacitive tiltmeters, and others. These have nothing to do with AI. Several sessions specifically had "AI" in their title, but I saw very little of that discipline in any of these papers. However, as I have noted in past reports concerning descriptions of experimental laboratory hardware, laboratory scientists exhibit a tremendous amount of creativity with which techniques are adapted or developed, and frankly I could not imagine how many of these solutions would have been discovered without intimate collaboration with the physical problem being studied. In that sense I agree completely with Zingales.

Where were the U.S. Participants? TC7 is a European-based organization, and so one expects a preponderance of European scientists. Nevertheless, it was disappointing not to see other Americans at an international English language meeting on such an important topic. I wondered about this; the conference organizers did not have any ready answers either. They claimed that some related work is done in the United States, but it is more heavily based on electronics than the broader type sensing of interest here. IMEKO also publishes a journal, *Measurement*; its editorial offices are in the United Kingdom. A scan through some issues show papers mostly from Europe but also from other places such as Australia and Japan; there is essentially nothing from the United States, and I wonder if Americans read it. (Not surprisingly, the Australian contributions are about intelligent measurement of coal dampers, etc.)

CONCLUSION

This seems to be a topic ready to take off. There is an excellent match between what we can measure and what one needs to compute based on these measurements. AI and related computer science technology is going to be adapted to help solve measurement problems. Not much has happened yet compared to what will occur. Sensors are getting smart in that they can perform substantial computation, but most of the "intelligence" is ad hoc. There are a few theoretical developments that are being pursued, but to me the field seems wide open and very attractive for fascinating collaborative projects between hardware and software researchers. The modest amount of AI I saw was mostly being described by the Europeans; with a few exceptions the Asian papers were much more application oriented, albeit very clever. At the moment it appears that the bulk of the work will likely be done by the scientists crafting the experiments, but people with more computer science training could learn a great deal about real problems in addition to significantly contributing in an important field.

MITSUBISHI ELECTRIC CORPORATION: ITS BASIC RESEARCH FOCUS

Some of Mitsubishi's research directions are summarized.

by David K. Kahaner

INTRODUCTION

Over the past year I have received assorted information about Mitsubishi Electric. My original plan was to gather this together and coordinate a collection of visits and discussions with research staff. I have not yet been to any of the corporate laboratories, though, and I have been worried lately about my data becoming dated. So I decided to put together a short sketch along with a few items of interest to me. I hope to follow up on some of the key research directions along the areas of my expertise.

Of Japan's three top general electric manufacturers, Mitsubishi Electric Corporation is the one that most heavily depends upon heavy electric machinery, with sales and manufacturing lagging behind in the areas of computerized information and electronics. Currently, its telecommunication and electronic device products comprise only 35% of the company's total sales. However, in order to push this ratio upward to the 50% range within the next 3 years and to move its heavy electric machinery manufacturing toward an electronic basis, the company now is trying to move rapidly toward the goal of becoming a general electronics manufacturer by restructuring.

The key factor in achieving this goal is making investment in research and development (R&D) its priority. Moriya Shiki, the company president, claims that

> Unless we increase the ratio of computerized information and electronic products, we cannot expect to achieve substantial growth as a company. The biggest task awaiting us is to come up with the means of realizing growth in the telecommunication and electronic device fields. For this reason, we will continue to intensify our R&D efforts and to push for increased investment in this area in spite of current economic downward trends.

The company claims that its plan is to increase within 3 years the business structural ratio of information, communication, and electronic devices to above 50% and within 10 years to 70%. Semiconductor and electronic device technology and information communication system technology are seen to form the nucleus of the basic technologies to support an advanced information society, and these are the areas into which Mitsubishi is pouring its efforts.

Vice President Oka predicts,

> Although the company has been called a general electric machinery manufacturer, it will be transformed rapidly into a general electronics manufacturer, and then into an intelligent system manufacturer.

To the company that is "strong in communication technology, but weak in computer technology," this has become the most important challenge to be met in the 1990s. In the early days Mitsubishi's R&D was like insurance, and as a result its importance was modest. Recently, though, upper management has seen the importance of this kind of activity and claims to be supporting it much more aggressively. After World War II, the Japanese economy developed along four growth industries: facility related, home electronics related, computerized information related, and consumption related; Hitachi and Toshiba focused on the first three. Mitsubishi grew in the equipment and facilities areas but not so rapidly as the other companies in home or computer/information--perhaps due to its dependence on heavy electrical manufacturing.

In the semiconductor and electronic device division, Mitsubishi ranks second, after Toshiba, in 1M DRAM and is among the top-ranking companies in the field of microcomputers and SRAM. The company is also very strong in the area of integrated "system building."

The majority of Mitsubishi Electric Corporation's research laboratories are located either in the western region (Amagasaki/Itami Districts, Hyogo Prefecture) or in the eastern region (Ofuna District, Kanagawa Prefecture). In addition, there is its Electronic Product Development Laboratory in Kyoto.

All together there are 13 office/ research laboratories under the Development Headquarters, with a total staff of about 3,300. The R&D costs for 1989 totaled ¥160B, a bit less than 7% of total sales. Oka claims that the company hopes to raise the ratio of the R&D costs to about 10% of sales with a similar percentage of research employees in the future, but doesn't see it ever exceeding this figure. He also claimed that one mechanism is to establish research facilities outside of Japan such as in the United States, and this technique has already begun.

The company has developed a technology map for the 1990s. Only a few of the projects are noted in Table 1. A brief description of some of the main laboratories and their significant projects follows.

CENTRAL RESEARCH LABORATORY (CRL)

The Central Research Laboratory has a staff of 450. Its role is to conduct research in important areas and be at the cutting edge in basic technology. By contrast the other laboratories focus on applications. Topics of current interest are biotechnology, neurotechnology, artificial intelligence (AI), optics, energy, quantum electronics, beam technology, and superconductivity. Seventy-five percent of the research is self-directed (versus 25% in response to requests). There are five basic technologies being looked at here (other laboratories are obviously also involved): (1) From bio to neural computers, (2) new devices on atomic/molecular levels, (3) user-friendly technology, (4) space, and (5) energy/environment.

Some examples of (interesting to me) research at CRL are neural information processing of sea mollusk, optical-neural computer on a chip (the company has already developed such a prototype that recognizes 26 alphabetic characters), and man-machine interfaces. For the last, the company has a new project to develop quantitative psychological measurement techniques to evaluate a system from a human psychological standpoint (also see my comments below). The company has used AI, cognition science, and various interface technologies. Mitsubishi also has a large space-related research program (space robots, large-scale expandable antennas, composite materials) and numerous acid-type fuel cell facilities.

Table 1. Technology Map for the 1990s

Field	Projects Planned for--			
	1991	1992	1993-95	1996-99
Cities/ Traffic	Electromagnetic ship	Rocket HII	FX pilot unit Techno Superliner Electric auto	Smart city Intelligent car navigation system
Consumer Electronics & New Media	Next generation portable telephone Hivision becomes popular	Housecleaning robots B-ISDN Digital video tape recorder	Quasi-microwave car phone DRAM recorder Moving-picture TV phones	Cordless home electronic units Communication & broadcast fuse
Industrial Electronics Device Software	Communication sample 16M DRAM Liquid crystal display elements mass produced 5th generation computer Practical multimedia Distributed systems	High temperature superconducting elements Photo exchange	Communication 16M sample 64M TFLOP computers practical	Communication 64M Nonsilicon Non Von Neumann TRON age Distributed processing

CRL is divided into about a dozen departments including the Basic System Research Division (focus on knowledge systems, cognition systems, design systems, etc.); Quantum Electronics Research Division (focus on opto-neuro-computers, quantum effect devices, etc.); and the "Special" Research Section (focus on all types of new computing). Of course, there are also groups in biotechnology, materials, plasmas, lasers, and a myriad of related technologies.

ELECTRO INFORMATION RESEARCH LABORATORY (EIRL)

Computer-related work is also going on at the Electro Information Research Laboratory (staff of 400). Major fields are (1) man-machine interface, (2) knowledge processing, (3) computer architecture, (4) system building, and (5) information networking. All the projects focus on "a cooperative information society," meaning user-friendly computing, computers that accommodate user needs, etc. In practical terms this involves research in multimedia and various interfaces; recognition (character, voice, and image)--for example, reading of blueprints--intelligent searching; and dialogs that can deal with ambiguity (via neural networks, fuzzy logic, and natural language techniques)--for example, a voice question and answer system.

EIRL's work in computer architecture has focused on working with the Institute for New Generation Computer Technology (ICOT) in the development of parallel scientific inference (PSI) machines, multi-PSI machines, and parallel inference machines (PIM) for (nonnumeric) logic programming (inference processing). At the moment PIM is running with about 250 inference processors, but the target is about 1,000 processors.

EIRL's cellular array processor (CAP) has 4,096 CPUs and can perform 20G fixed point additions (8 bit) per second. To generate these high speeds, CAP uses a 16-Kbit GaAs memory developed at the LSI Research Laboratory (see below). Mitsubishi sees CAP's main application to image processing (satellite data), or perhaps document retrieval. This computer has no relation to Matsushita's AP1000, which was also originally named CAP.

In the area of knowledge processing, major research themes overlap with the ones mentioned above, i.e., AI, expert systems, natural language processing, and high-speed inferencing. A 50,000-word Japanese-English machine translation system is being developed. One expert system example is Solomon (solution-oriented systems design methodology based on knowledge), which deals with solution-oriented system planning, classifies problems into 13 types, and is claimed to use operations research (OR), AI, and system engineering methods. I haven't seen this in operation. The company is also keen on a software design support system, PPK (Problem Product Knowledge), using Hypertext. Finally, this laboratory is very active in communication technology, multimedia (again), B-ISDN, satellite communication, high definition TV (HDTV), etc. One interesting project is related to decreasing the frequency of errors in satellite communication, using new coding methods. Mitsubishi claims that this method has reduced the occurrence of errors to 1 per 100 Mbits. There are also a large number of what I call "enhancement" projects, such as those related to still picture TV telephone, increased brilliance for large screen TV using scandium oxide cathode, biofeedback for heating blankets, etc.

Cooperative and friendly computing is a serious theme at a great many Japanese laboratories, and I would expect to see a significant number of interesting results from industry's desire to make products more amenable and hence more marketable. Reading about Japanese plans in this area often leaves Westerners with an uncomfortable feeling, perhaps like "vaporware" in computers. I think that this is mostly due to differences in vocabulary and world view. It isn't often we hear hard-boiled Western managers talking about "enriching human life both materially and spiritually as a keyword of future consumer lifestyle and consumer behavioral changes," but this is typically Japanese (or perhaps Asian?). However, there is no doubt something in this style, as attested to by the many Westerners who like Japanese products.

CONSUMER LIFESTYLE SYSTEM RESEARCH LABORATORY

Mitsubishi has the Consumer Lifestyle System Research Laboratory (more than 30 years old now) with more than 200 researchers thinking about these issues. This laboratory used to be entirely directed toward home electronic research, but this is now less than 50% of the effort, the remainder going toward "human technology and intelligent systems." About 30% of this work is independent research and about 70% is related to requests from factories and operational divisions. More than 15% of the research staff are women, and Mitsubishi feels this will enhance the company's sensitivity to female needs. This is the laboratory that is most directly involved with a 1990 Ministry of International Trade and Industry (MITI) 10-year project, "Application Technology for Human Sensitivity Measurement." Research themes here are (1) air, e.g., air flow, sound and temperature sensitivity controls; (2) illumination; and

(3) environment measurement sensors. There is also joint work with CRL in "psychological quantity measurement" where attempts are made to measure the stresses that are inflicted on humans by machines.

LSI RESEARCH LABORATORY

Mitsubishi also has an LSI Research Laboratory, a photo/microwave device laboratory (staff 180), and a customized LSI design and development center. The LSI Research Laboratory has 550 scientists and technicians and is thus larger than CRL. At the moment Mitsubishi is behind Toshiba in DRAM production, but the company hopes that research at the LSI laboratory will enable it to catch up in 16M and 64-Mbit DRAMs. With work in this area as well as ASIC (such as 4-Mbit SRAM and other gate arrays), Mitsubishi is planning to double the number of scientists at the LSI laboratory. The company feels that general purpose multiprocessing units (MPUs), digital image processing, and HDTV will be major fields in the 1990s. The company also hopes that TRON will take root [see my report "TRON (The Real Time Operating System Nucleus," *Scientific Information Bulletin* 16(3), 11-19 (1991)]. Naturally the company is also working toward Gbit chips. In optical technology, Mitsubishi emphasizes that the company sees directions as (a) short wave, (b) long wave, (c) optical output, and (d) coherence. In the microwave the company see devices mainly composed of GaAs ICs moving toward (a) diversification, (b) low noise, (c) high frequency, (d) high output, (e) high reliability, and (f) low costs. Important points in future technological development will be: new materials (III/IV group elements), device structures that can accommodate some integration and offer high level of uniformity, and miniaturization processing technology. In this last area, especially, the company is working on the introduction of wafer process techniques into optical device miniaturization process technology.

Mitsubishi has a view on differing U.S./European Community (EC)/Japan R&D capability, at least in the area of VLSI.

> The fact that Japanese manufacturers are strong competitors with U.S. and EC makers in super VLSI technology and in [the] semiconductor/electron device field can be attributed to their ultra-miniaturization process technology and excellence in production technology. U.S. and EC makers have proposed epoch-making concepts and architecture, which revolutionizes existing production technology and systems, as demonstrated in their mass production technology (i.e., conveyor systems, copying machines, etc.); automation technology (i.e., NC machines, machining centers, robotics, etc.); and information system technology (i.e., MAP, CIM, etc.), but they wind up being beaten by Japanese manufacturers in the important field of manufacturing/processing technologies, however. Japanese makers, on the other hand, may not be able to come up with innovative concepts and architecture; however, they are the best in the world when it comes to the production technology which translates these ideas into actual products. Currently Japan is ahead of the U.S. in implementation of MAP and in practical application of CIM.

That is correct.

VIRTUAL REALITY

Comments on virtual/artificial reality research in Japan are presented.

by David K. Kahaner

ITRODUCTION

Virtual reality (VR) or artificial ality (AR) is now a "hot" topic both the United States as well as in Japan; sults are appearing almost daily. ather than try to wait until a substan- al body appears, I intend to distribute iort notes on interesting activities as learn about them.

Most of the VR experiments I have :ad/seen involve some kind of hat or elmet covering the eyes of the wearer/ ser. Small liquid crystal displays (LCDs) 'ithin give a three-dimensional (3D) isplay of a computer-generated scene. 'ransmitter/receivers on the helmet llow detectors (mounted in a fixed osition nearby) to determine the exact)cation and orientation of the user's ead. This information is passed to a omputer that changes the helmet image ı concert with the head's changing iewpoint. It is also common to allow he user some other means of manipu- ıting the scene, for example, by giving im/her a steering wheel or joystick, tc. Instead of a helmet some systems se a very large display such as would e viewed while looking out the win- ow of a plane or ship, but smaller isplays are far cheaper and have ther advantages. At the moment the ombination of resolution of displays nd computing power on the systems enerating the images leaves much to e desired in terms of image resolution, ut this will improve rapidly. There is lso a problem with time delay between ead movement and scene movement ecause a great deal of computing needs ɔ be done to generate even small motions, and this obviously increases more than linearly with resolution improvements. Nevertheless, most users of even these low-resolution systems experience a strong sense of realism. (Wide-screen cinema can also disorient viewers, so this effect is not too surprising.) Many VR systems also incorporate a "data-glove," a fabric glove with sensors attached that a user will wear; a computer-generated image of the glove is placed in the visual scene and is made to move in concert with the user's motion of the gloved hand. As the user moves his/her hand in space, the image glove can be made to grasp objects within the computer-generated scene and move them around.

Research in VR seems to fall into several broad categories:

(1) Experimenting with the hardware, software, and the computational models in order to enhance the sensations of realism to the user. This involves improving the display hardware and understanding the meaning of "realistic sensation" in terms of visual factors such as field of view, resolution, stereo, audio, etc.

(2) Developing applications.

(3) Developing tools to aid researchers and users.

Applications are limited only by the imagination of the researchers; games are the obvious first ones, but there are many opportunities related to training, from pilots to surgeons.

VR is at the intersection of computer graphics and human computer interface and is a natural extension of both. For example, Yusen Marine Science has developed a simulator for maneuvering of large container ships. The simulator uses six workstations for setting various navigation environments, which are reproduced on a several large screens allowing a 240° field of vision. The screens are in a chamber patterned after a ship's bridge and the view on the screen is changed to conform with steering and speed changing operations. Human factors such as nervousness, misjudgments, and misconceptions are incorporated into the system to enable trainees to get more realistic simulations.

VR LABORATORY AT THE UNIVERSITY OF TOKYO

Profs. Yoshio Tsukio and Michitaka Hirose have developed a sophisticated laboratory at the University of Tokyo for experiments in VR.

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As at many other places (also in the West), theirs contains a collection of purchased and built-up equipment to allow them to (a) experiment with existing VR techniques and (b) build upon these for new work. Most of their purchased equipment is from the United States, although I was told that they are considering changing to some United Kingdom products that they felt were more cost effective. They admitted that at the moment the United States is furthest along in this area and has some of the most creative ideas. But this is certainly not the only laboratory studying VR in Japan, and not even the only one at the university. Hirose explained to me that most of the large Japanese companies have some hardware/software research in general VR topics. He mentioned specifically NTT's Human Interface Laboratory, the ATR Laboratory in Kansai (see below), as well as Matsushita and Fujitsu. These companies are ready to jump in once the market solidifies I was told.

At the University of Tokyo's "sub-urban" campus, Profs. Fujimasa and Tachi also have a VR laboratory associated with the University's Research Center for Advanced Science and Technology (RCAST). There is also a committee composed of more than a dozen university researchers who coordinate, informally, activity in VR. Participants are from Tokyo, Keio, RCAST, Kyoto, the Tokyo Institute of Technology, Tsukuba, etc., and include computer scientists, engineers, medical doctors, and others. There is also a journal, *Human Interface News and Report*, published several times each year, that contains the proceedings of the annual Human Interface Conference, as well as other papers and lists of meetings. Japanese are very active in the development of computer games and there is already at least one product incorporating a data-glove, although Hirose told me that the company that manufactured the glove has gone under and that large quantities of them are now available very cheaply.

Projects at Hirose's laboratory are described briefly below.

See-Through Helmet-Mounted Display

The idea is to optically superimpose a virtual 3D object onto a real environment. The system consists of Sony view finders, a lens system, and half mirrors; the image displayed on the view finder screen is focused about 1 meter before the eye using the lens system and half mirror and has a view of about 20°. In other head-mounted displays, narrow fields of view can cause loss of spatial direction, but in this system the user has a "real" world with which to orient.

Lightweight Helmet-Mounted Display (HMD)

Of course the lighter the better--ideally no more than eyeglass weight is desired. Hirose claims they have developed the world's smallest HMD, with 5.0- by 7.5-cm LCDs having 200 by 300 line resolution and weighing 170 grams including cables. I tried this system. It works, but the display is not illuminated, and so is only visible in bright background light; nevertheless, its size and weight make it an impressive step forward.

Virtual Holography

The idea is to avoid using either a helmet or a data-glove. A key application here is to computer-aided design/manufacturing (CAD/CAM) systems that require higher resolution than available with current HMDs. Hirose has substituted a conventional stereo cathode ray tube (CRT) but uses a head-tracker to allow the kind of interaction usually associated with a helmet. This system cannot generate the sense of an all-encompassing universe sometimes associated with HMDs, or very large screens that are very exciting visually, but it can generate sophisticated and high resolution displays in small regions of space, and these might be perfect for detailed CAD/CAM applications. In addition to high resolution, this system also adds a mechanism for providing tactile feedback. Data-gloves can move around freely in the air even when the computer-generated hand hits a solid object. Hirose's system requires the user's finger to be placed in a magnetic ring that is free to move within a guide. Four magnetic sensors located on the ring measure the location of the finger and move so as not to touch the finger. However, once the finger intersects the computer-generated object, motion to the object's surface is disabled by locking the unit. My sense is that force feedback is an essential element in providing effective applications of VR technology. I am not aware of too much work in this direction in the United States; the Japanese are doing advanced work in tactile feedback.

Software Visualization

Hirose's idea here is to use VR to generalize flow charts and block diagrams by adding a third dimension. His applications are to large, complex software systems such as network control software. (Hirose's example is the regional power system around Tokyo.) There are many other attempts to simplify programming of such systems, and a graphical programming environment is common. He wants to fuse both block diagrams and time into a three-dimensional representation. The idea would be that users could directly manipulate the blocks, move around the 3D representation, etc. Several tools are being developed.

(1) Virtual editor to define, modify, and delete processes and message passing among processes.

(2) Virtual measure/ruler to measure the exact synchronization of processes.

(3) Virtual path finder to locate and display the critical path to determine the total network throughput for a given network.

(4) Network simulator.

A virtual 3D object is necessary for this kind of system, and thus this represents a very nice application of object-oriented programming. A prototype is being developed using an Ikegami 80-inch, 120-Hz stereo projector with CrystalEyes LC glasses that generates a realistic 3D work space. A VPL DataGlove through which the user can handle virtual objects runs under an Iris 4D 210 VGX workstation for graphics and a Sun Sparc station for text. Hirose is planning to add his virtual holography techniques in order to enhance the sensation of handling processes in 3D. Personally, I have a "show-me" attitude about this approach. But having said that I hasten to add that understanding distributed computing is so difficult, and there are so many look-alike efforts, that a really new idea like this one is definitely worth cheering for.

Virtual Physical Space Simulator

This is more game-like. Hirose is thinking about altering some physical parameters (gravitational constant, air viscosity, light velocity, etc.) interactively while viewing a virtual world. His audience for this seems to be mostly students.

Hirose is planning to describe some of his latest work at Human Interface '91, (23-25 November 1991, Tokyo) and has a preprint that will be available at that time. (A symposium on VR is also planned for 31 October-1 November.) Many of the papers from Hirose and Tsukio's laboratory are written in English (this is not the case with most of the other Japanese research in this subject) and Hirose can be contacted via electronic mail.

ATR LABORATORY

Work at the ATR Laboratory in Kansai has focused on developing an effective video conferencing system as part of a larger project, "Fundamental Research on Intelligent Communications." In ATR's system, a user sits in front of two large lenticular screens that form a "V" facing him, with images of other people on the screens generated by liquid crystal projectors. ATR wants to enhance the sense that the people are really in the same place by improving their sense of "being there." This is done by monitoring eye movement of the participants and adjusting the images synchronously. At the moment the system reflects light off a user's pupil to follow movement of the cornea (noncontact eye movement detection). For related experiments, there is also a contact-type detector that is mounted on a pair of eyeglasses. This is one of the more basic research projects in the VR field, although its application is very specific.

CONCLUDING REMARKS

At the recent Computer World '91 in Osaka, we were treated to a description of the future of VR by Robert Jacobson of the University of Washington. Jackson commented that fundamental breakthroughs are not needed and that research capabilities were well distributed, but that industrial work was undercapitalized. He felt that by 1995 the industry will sort itself out and by 1999 various high end markets will become evident. I do not think that anyone in the audience disputed the directions that VR will take. However, I doubt very much that today's computer graphics leaders are simply going to sit around and wait for the VR guys who are now working in their basements or university laboratories to gobble up their users. What is more likely is that the graphics vendors with resources to commit to research and development will incorporate more and more VR into their own products by internal development, joint ventures, acquisitions, etc.

COMPUTING AND RELATED SCIENCE IN AUSTRALIA

A summary of high performance computing in Australia is presented.

by David K. Kahaner

INTRODUCTION

During July 1991 the author spent several weeks in Australia, attending the International Conference on Computational Techniques and Applications (in Adelaide) and visiting a number centers of computation and computing science in Adelaide, Melbourne, Canberra, Sydney, and Brisbane. These are all on Australia's south and eastern coasts, located (in U.S. terms) approximately from New Orleans to New York. This report summarizes the situation as represented by those visits.

Australia is almost as large as the United States yet has only about 1/15th as many people (17,000,000). Most of the population lives in and around a few large cities (metro Sydney has a population of over 3,000,000). It is expensive and time consuming to build communication links between cities. Air travel is the only really practical method of moving over such large distances. Manufacturing has not yet taken root to the extent that the Government would like, and the Australian economy is still largely based on extractive industries. The recent global recession has been strongly felt in Australia, and unemployment is around 9%. There has been quite a bit of foreign investment, although the country is still perceived as one with significant labor strife. Japan is investing heavily (as is the United States), and this has led to mixed feelings from Australian citizens, although it makes sense for Japan and Australia to cooperate. Australia can use the capital. It could also use more people, but there has not been much direct immigration from Japan. Japanese enjoy vacationing in Australia because it has seasons opposite from Japan's, has much of the wide-openness of the United States (in geography and style), and is also perceived to be safer. July is winter in Australia; in the south this means nighttime temperatures at or below freezing. Brisbane, halfway up the coast, is a bit warmer but not warm. The Japanese want to transfer their technology; Australia is an excellent place to try out products and services aimed at the United States and European Community (EC). Sydney is closer to Tokyo than Los Angeles, but not close; Los Angeles to Sydney is more than 14 hours and Tokyo to Sydney is more than 10 hours. Travel between Japan and Australia is mostly north-south, and the two countries have time zones in common.

Science in Australia is an alphabet soup blitz of acronyms. The same names came up repeatedly associated with different institutes. Any number of the scientists I spoke to began their conversation by drawing organization charts to assist me (and perhaps themselves, too). A large number of the organizations are new, or are newly restructured. In this report I have tried to summarize the most significant of these, and the report has been circulated within Australia for corrections. But readers are advised that there is a tremendous amount of energy in Australian science now, and in particular in computing, and there are certain to be plenty of changes over the next year or two.

Foreign investment in Australia occurs in direct ways such as purchasing real estate, hotels, etc. Of interest to scientists is the "offsets" legislation. In this, foreign companies with substantial sales to the Australian public sector (government, universities, laboratories, etc.) are required to spend 5% within the country on research and development (R&D) activities. This is a complicated and controversial program; many scientists I spoke to felt it was often ignored or satisfied in a pro-forma way. Nevertheless, given an avenue to spend this money profitably, most companies are willing to participate. Boeing, Fujitsu, and IBM are specific examples with respect to computing. Boeing has been involved over the past few years studying the possibility of providing supercomputing services and research, although whether this will occur is questionable. Fujitsu is helping to support a substantial parallel computing effort at the Australian National University in Canberra. Fujitsu's corporate mission is "to become the major force in the Australian and New Zealand computer and communication industry." IBM is providing major support to Victoria's Strategic Research Foundation (SRF) with a 3090, RS6000s, and research funding. (NEC has no supercomputing presence in Australia, although I was told that the company is heavily involved in communication, particularly PABX.) More details are provided in the sections on supercomputing and on the Australian National University.

Most Australian citizens can trace their roots to Great Britain (England, Ireland, etc.), and many institutions and intellectual predispositions are strongly influenced by this background. In the fields of computing and applied mathematics, this means that scientists share the British view of careful hard analysis in the tradition of Hardy, Copson, Turing, Whittaker, Wilkinson, etc. Thus very strong analytic skills are coupled with excellent physical insight. In other words, applied mathematics means applied analysis, asymptotics, modeling, etc., not applied functional analysis.

University science in Australia occurs at large state universities (there are eight Australian states including two territories) and the single Australian National University in Canberra, the capital. There is one (new) private university (Bond University) near Brisbane, but it has no track record yet. The Australian Government runs the Commonwealth Science and Industrial Research Organization (CSIRO), distributed in many laboratories throughout the country, and also the Defense Science and Technology Organization (DSTO), which also runs laboratories in various places. Local states have set up institutes and technology centers, but there is not much large scale industrial research, a situation that the Government is trying to alter. Recently, the Australian Government has set up funding for up to 50 scientific centers of excellence, with a long enough support base (7 years) to give them the opportunity to really establish themselves.

There are a number of Australian computer scientists, numerical analysts, and modelers who are world renown, including M. Osborne, S. Elhay, R. Brent, B. Noy, J. Kautsky, I. Sloan, N. Stokes, and others. Their work is comparable (in direction and quality) with the best in the West. There are also a few special strengths in Australian computational science. Australia has one of the only Fujitsu AP1000 parallel processors available outside Japan, and scientists interested in learning about Japanese parallel processing could not do better than arranging collaborations with Australian colleagues who are using this machine. There are also two Fujitsu VP2200 vector supercomputers and a software development effort, which is mostly open and accessible. Australia also has a stronger (per capita) interest in symbolic and symbolic-numeric computation than the United States, and perhaps stronger than the EC. Interfacing symbolic computation to numerical software is becoming an important research area. Australian projects such as Senac, Intercal, and GenTran have made significant progress using very high quality numerical software such as in the Nag library. There are excellent opportunities for research collaborations with these projects. Finally, Australians are keenly aware that their country is an island (although a huge one). The amount of science activity related to modeling weather, oceans, etc. is very great. Here is a typical example. In the Mathematics Department at the University of New South Wales (Sydney), of 13 Ph.D. students, 8 list some aspect of ocean modeling as their thesis topic. Of course, the mining industry also generates a great deal of mathematical and computational problems, but many of these are being studied by scientists who are at the universities or government research laboratories. Combined with the high quality traditional analysis and (until recently) a dearth of computing capabilities, the scientific establishment is primed for collaborations with Western researchers.

Australian scientists are already well connected with their peers in the United States and Europe. There is no lack of mail and electronic communication. Scientific exchanges and visits are common, but distance makes them nontrivial and expensive. Sabbaticals are comfortable because of the common language and customs; strip malls near Melbourne look very much like they do near Washington, and parts of Sydney are indistinguishable from parts of downtown London.

Networks within and to/from Australia, while not at the bandwidth available in the United States, are perfectly adequate for mail. Electronic communication outside Australia is through a 128-Kbit/s line to Hawaii or directly to the U.S. mainland (my Email message to Japan from Melbourne went through to the United States first). IBM, as part of its support of collaborative research at SRF's 3090 installation, wants to upgrade the link through Hawaii (see also the section on SRF). Most large universities have access to 48-Kbit/s AARNet (Australian Academic and Research Network), and others are coming on line rapidly. There is at least one 256-Kbit/s and several 2-Mbit/s links. Bandwidth is being increased along the Sydney-Melbourne-Canberra-Brisbane lines, facilitating access to computing resources in this area from other parts of the country. The University of New South Wales and the University of Sydney have a 10-Mbit/s microwave link, and there is also a 10-Mbit/s link between the Cray Y/MP in the Melbourne service bureau and Melbourne University.

For a country with Australia's population, there has been a large run-up in supercomputing capability in the past few years. While the country has had a few large scale computers for years, the amount of computing available to the average scientist has been low. Now there are about half a dozen Cray or Fujitsu VP machines in the country. There is one Connection Machine, a number of Convex computers (three are at CSIRO, one at the Defense Forces Academy, two at universities in Queensland, and perhaps other places), three or four (MP-1) Maspars, and at least one large 3090 going in this year. All supercomputers are in the public or military sector or in service bureaus. There are none in the "real" private sector. In fact, except for some seismic processing, there is still very little supercomputing interest in Australian industry and commerce. Several Australian companies buy supercomputing time on one of the available local machines or have special lines that make U.S. machines available from a corporate resource. There are still not enough supercomputing cycles available for everyone's needs. Also, the distribution of resources is not uniform, although the cities of Melbourne and Canberra are well supplied. In fact, Canberra has a tremendous amount of computing capability and a great deal of momentum. At the same time, a service bureau in Melbourne with a Cray Y-MP/216 is having a difficult time finding buyers at commercial rates.

There are essentially no Australian computer products except for some PC assembly firms and Labtam, which makes X-Windows terminals. However, the Government is trying to inject action into the information technology business in a number of ways (some of these are detailed below). In fact, the Department of Industry, Technology, and Commerce (Ditac) has given grants up to $A2.4M ($1.9M) for generic technology projects involving collaborative research between groups in industry, universities, and research institutes. At the same time, I was told repeatedly that in the past the Australian Government has not been viewed as really encouraging the kind of R&D that leads to successful business, and I was given several anecdotal stories about projects that were allowed to go only so far and then more or less withered on the vine, until their proponents went outside of the country. This was seen as related to the egalitarian (everybody equal) ethic, which is still very strong in the Government and within the general population (passengers ride alongside taxi drivers, rather than in the rear seat).

Such statements by scientists were difficult for me to understand, given the heavy emphasis that the Government places on practical R&D. For example, the major national laboratory, CSIRO, now must bring in 30% of its revenue by outside contracts, and everybody that I met in this organization is scrambling to find external sources of funding. There are also examples of successful Australian research activities. For example, Interscan is a Sydney manufacturer of microwave aircraft landing systems (MLS). The company is 100% owned by the Australian Industry Development Corporation. The company's main product was originally developed by CSIRO radioastronomers in the early 1970s. (By 1998 all 2,500 major airports around the world must have MLS systems installed.) In 1984 Interscan lost a very large and controversial bid to Hazeltine in the United States (in 1989 the Federal Aviation Administration (FAA) canceled the Hazeltine contract for default) but has won bids in Spain, Australia, and recently in China (Xian Research Institute of Navigation), as well as a few systems in the United States.

The Australian Government may have been slow to push commercializable R&D in the past, but it appears to me that the situation has recently changed significantly.

SUPERCOMPUTING IN AUSTRALIA

Australian scientists have had large scale computers for many years, from a CDC 3600 in the early 1960s, to a 6600 in 1969, eventually a 7600 in 1973, and then a Cyber 205 in 1984. The University of Melbourne installed a CDC 990 in 1986 (this was the top of the Cyber line), and the University of New South Wales (Sydney) installed an IBM 3090-150 (later a 180 with VF) in 1987. Also in 1987 the Australian National University installed a Fujitsu VP50 and shortly after that a VP100.

But in the late 1980s there was a significant effort to do more, and various reports and position papers were written. The first Australian Supercomputer Conference was held in December 1988 and there were hopes that a national supercomputer center would be established (this never happened). In 1987 a private company (Leading Edge) was formed to be Australia's first commercial supercomputer service bureau with a Cray X-MP. The company's particular expertise was in seismic processing.

The 205 installation was having expected problems, not the least of which was a lack of adequate support staff, a complaint of many U.S. supercomputer centers, too. Eventually this machine was replaced by a Cray Y-MP2/216 in March 1990, which was installed at Leading Edge, effectively replacing the X-MP. This Y-MP is shared by CSIRO for their researchers, Leading Edge for sale, and Cray Research for its own use and to foster interest in supercomputing. Two Melbourne universities have arranged for some of Cray's time and are using it very enthusiastically. There was also an air-cooled ETA-10P for a short while at the Bureau of Meteorology. It was installed in December 1988. Even after CDC decided to stop producing ETAs, there was an agreement to upgrade the 10P to a dual processor, but the computer was dropped during shipment, and since it could not be replaced, it was removed and replaced with a Cray X-MP 14SE in July 1990. Finally there is also one Cray X-MP at the Department of Defense and there might even be a second one installed there.

In 1989 Boeing submitted a proposal for establishing a National Supercomputer Facility including a high-end machine (such as a Y-MP), support, communications, etc., based upon Boeing's experience running successful supercomputer centers, such as the one in Huntsville, Alabama. There have been a number of iterations of this proposal, and it has been on and off since it was submitted. Several Australian scientists told me that they felt that Boeing's involvement has actually slowed down supercomputer acquisitions by keeping other possibilities on hold and that will probably be true if nothing comes of the proposal. There was also an honest difference of opinion as to whether a profitable activity for Boeing should count against offset obligations. (I'm not in a position to judge any of these issues.) Boeing was also involved in a proposal for the installation of a Convex C240 in Queensland at CSIRO's Geomechanics Division that will be upgraded to a 3250.

In addition to the 3090 at the University of New South Wales, the State of Victoria has established the Strategic Research Foundation (SRF) in Melbourne, arranged to have an IBM 3090-400J installed this year in Melbourne, and allocated funds for some research institutes. The 3090 will be associated with an Advanced Computing Institute, and a Convex C210 will be used for a Biomolecular Research Institute, also administered by SRF. Eventually the 3090 will run AIX, but initially it was installed only with MVS. Scientists have told me that IBM is hoping to have a major Asian research facility to perform research similar to that going on in Bergen, Norway, or Ithaca, New York. The 3090 will be the twin of one at the Cornell supercomputer center, and it is reported that eventually the facility will be very substantial. As this is a brand new operation it is still underused, and many of the software tools are only slowly being installed, but usage will grow rapidly. (A relatively slow start-up has made this installation controversial, as scientists who need supercomputer time wonder why they cannot access the new machine.) See below for more information about SRF.

Until recently the Central Government has not been a driving force for supercomputing. Probably this had to do with division of responsibility between the states, distances, funding priorities, and related items. In 1987-88 this seems to have changed, but the Government is still not clear on whether or not it wants a national facility. The Australian National University (ANU) has more computing resources than any place else, but this is definitely not a national facility. In fact, a recent proposal to the Government for computer time commented that "only a small percentage of time on these facilities [ANU's] are available to outside users." Naturally, ANU would like a national supercomputing facility (located there, of course), and just as naturally many scientists in other locations would rather have better local facilities.

The argument goes the other way, too. Although some Australians would like to see a spread of machines rather than a national site (at ANU or anywhere), there are plenty of people (including the author) who subscribe to the view that Australia cannot afford more than one really large system and that the best approach is to have such a system plus killer-workstations, not a spread of mini-supers or weakly configured supercomputers. This view may become even more widespread as people move off Vax-class machines onto RS6000s and other fast small machines.

In the meantime, the Government is allocating money to various universities for super and parallel computing activities, and it has initiated a competition for parallel computing resources supported by the Australian Research Council (similar to the U.S. National Science Foundation). (My Australian colleagues explained to me that such allocations of funds are very indirect and that actually universities make the ultimate decisions about this research.)

As an example, ANU, the University of Queensland, the University of Melbourne, and the Royal Melbourne Institute of Technology have recently received $A1.3M ($1M) for cooperative research and training in parallel computing. As another example, a Sydney Regional Center for Parallel Computing has been proposed [almost $A2M ($1.5M) over 5 years] by a consortium of universities in the Sydney area based upon an 8K CM200 from Thinking Machines. The major applications are seen to be computational fluid dynamics (CFD), climate modeling, oceanography, statistical mechanics, and field theory, and the proposal lists almost 40 scientists who are seriously interested in access. Almost all these people are application scientists, not computer hackers. If they get the grant I hope they are aware of the time commitment such a project entails. I discussed this during a short visit to the University of New South Wales, in Sydney, whose researchers will be important parts of such a center. In the Mathematics Department, at least, there is substantial need for high performance computation. The staff is working in various aspects of fluid dynamics, nonlinear dynamics, oceanography, and numerical analysis. For example, I. Sloan, whose work in integral equations is very well known, is essentially doing theoretical numerical analysis. Typically this requires a computational partner for experimentation, verification, etc., and this can lead to a very large demand for computing resources. But without such a partner I wouldn't expect that much computing will get done.

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Another example of the kind of computing needed at the university was given to me by

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Monash is a large (25,000 students) university outside Melbourne, with more than 40 math faculty. Monaghan's interests, as are others in his department, are related to astrophysics, general relativity, and metrology. One significant approach for cosmological calculations that they have developed is termed Smoothed Part Hydrodynamics (SPH method), and this was reported in several issues of *Computer Physics Reports* in 1986 and 1987. (This work began as a collaboration between R. Gingold and Monaghan in Cambridge, U.K., in the mid-1970s. In addition to work at Monash, Geoff Bicknell and Gustav Meglicki at ANU have also been developing and using SPH and some serious simulations have been done; the new VP2200 at ANU in Canberra will be useful here.) Typically they have no explicit numerical analysis experts but develop techniques as needed during the study of individual problems. (Clearly as represented by Monaghan, the department has a very physics-oriented flavor.)

Monaghan's department has a collection of Vaxes, RS6000, Silicon Graphics, etc. but needs access to larger machines for studies of cyclones, star formation, cosmology, and the solar system. There is also a great deal of algebraic and symbolic computation (typical of the type of mathematical physics they are doing), and Monaghan claims that they also have a substantial interest and expertise in graphics for their applications. There are also computing needs for designing courses, but I suspect that most of those could be met with local resources. Monaghan has applied for support for new parallel computing and is also hoping to get time on one or more of ANU's machines.

Finally, the Australian Nuclear Science and Technology Organization (ANSTO) outside Sydney has just received a Fujitsu VP2200 (as of the date of this report it had not been opened to users) and will sell service on the machine. (This is a joint venture between ANSTO and Fujitsu.)

So, looking in from the outside, quite a lot has happened in just a few years. There is a concentration of computing on the east coast and the need for more cycles in other places. Researchers without access to enough computing cycles have been trying to reorient their work away from traditional large scale computation onto workstations or killer-micro parallel machines, but this might easily turn around if supercomputing resources became available. There is some scrambling for available money and complaining about who got what. Canberra (ANU) has certainly received the biggest fraction of the high performance computing cycles so far, primarily because the university made a firm commitment early and diverted internal resources to it. Industry has yet to be engaged, and there is still a great deal of educating to be done. The iron and aluminum industries as well as the medical research community are potential supercomputer users. Marketing people will likely try to convince these groups that their current thinking is 1950s, e.g., too small. It is difficult to imagine selling more than a very few multimillion dollar computers in Australia, but there ought to be room for up to a couple of dozen smaller machines [say up to $A1M ($769,231)], and there certainly needs to be a big, high-end machine somewhere. Finally, it remains to be seen if selling supercomputing service (or cycles) will be profitable. In the United States, selling cycles has not proved to be profitable.

The Fourth Australian Supercomputer Conference (4ASC) will be held 2-5 December 1991, at University Park Hotel at Bond University, jointly sponsored by the four universities in the area (Griffith, Queensland, Bond, Queensland University of Technology). This is on Australia's Gold Coast south of Brisbane. Five of the eight keynote speakers will be from the United States (Hillis, Joblove, McRae--an Australian, Neves, Steele), but there will be heavy Australian participation, if only to learn. Jerard Barry (ANSTO) will also be running a 2-day workshop before and after the conference. For information, contact

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or one of the two chairs, Prof. Gopal Gupta (James Cook University) [gopal@sheila.jcu.edu.au] or Prof. Paul Pritchard (Griffith University) [pap@gucis.sct.gu.edu.au].

I am in debt to

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for providing me with a great deal of this historical information.

AUSTRALIAN NATIONAL UNIVERSITY (ANU), CANBERRA

The country's only national university is located in its capital, a city that did not exist until 1913. Even by Australian standards it is not a populous city. It is inland, an hour's flight from Melbourne or Sydney, with somewhat cooler summer and colder winter weather than either of these cities. I found it to be a very beautiful small city surrounded by green hills and parkland and with a large (man-made) lake in its center. ANU is spaciously laid out and lushly landscaped, with parrots and many other birds in abundance. About 7,400 students and almost 1,000 academic staff are involved in the usual diverse range of university programs in the arts, sciences, engineering, law, medicine, etc. Only about 50 full fee-paying students are non-Australian, and most of these are from Hong Kong or Singapore.

Associated with ANU is the ANU Institute of Advanced Studies (IAS) (modelled roughly on Princeton's), where research is performed and graduate and postgraduate students can work. Some faculty members at ANU have joint appointments at one of the research institutes within IAS, as well as normal faculty appointments. The institute is approximately a $A150M ($115.4M) institution with about 1,200 graduate students. In fact, the normal ANU faculties are rather like the tail, with a budget of $A60-80M ($46.2-61.5M), supporting about 6,000 undergraduates.

ANU has about 25% of all members of the Australian Academy of Science and about half the Fellows of the Royal Society. For comparison, the government science laboratory CSIRO has about 15% of the academy's members.

This section focuses entirely on computing and associated research, but I should mention that associated with ANU is ANUTECH, a company that tries to generate outside support for university research, looks for commercial opportunities, etc. Last year ANUTECH processed more than $A20M ($15.4M) in grants and should be the contact point for general questions about research activities. Contact

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In the area of computing there is no question that ANU is the best endowed of all universities in Australia. It made a strong internal commitment in 1987 in this direction (people and money) that has now begun to pay off. Lumping together equipment that is either on the campus or at nearby CSIRO institutes, we can mention the following. There is a 16K PE CM-2, a Fujitsu VP2200 supercomputer, as well as a Fujitsu AP1000 64-node mesh-type parallel processor. The latter is to be upgraded (September 1991) to 128 nodes. Thus, the university now has three over-1-GFLOP machines running. There is also a high end Silicon Graphics 4D/21 with VGX graphics, a Sequent Symmetry 16K processor, a Maspar with 1K processors, some transputer arrays, and an impressive range of Suns and personal computers (PCs and Macs), all networked together. Some of the equipment has arrived only recently; it is not all shaken down and users are just beginning to appear. For example, while I was there the VP2200 was being brought up for the very first time. This is also running a new Unix release, and some headaches are natural.

Actual funding of ANU is not that dissimilar from state universities--the State Governments have formal control over them, but in fact the money comes directly from the Federal Government, thus both formal and economic links with the Feds. There are many people in Australian science who believe that (in advanced computing) ANU lives in clover from the Federal largess, but everyone I met in Canberra made it a point to explain that the university chose its direction in 1987 and has committed substantial internal funds since then, as well as made a number of creative deals with vendors such as Fujitsu.

Of the equipment on site, the most interesting to me were the two Fujitsu machines. To the best of my knowledge this facility makes these computers more accessible to public researchers than anywhere else in the world. The AP1000 is housed in the Computer Science Department, while the VP is located in the Supercomputing Facility.

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CENTER FOR INFORMATION SCIENCE RESEARCH (CISR)

An effort has been made to organizationally coordinate the computing and related research activities by creating an umbrella organization.

Center for Information Science Research (CISR)
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(McRobbie is also credited with being the sparkplug responsible for the runup of computing capabilities at ANU.)

CISR brings together various ANU research projects and departments as well as several groups from the Government's CSIRO.

ANU:

- Automated Reasoning Project
- Department of Computer Science
- Center for Visual Sciences
- Computing Sciences Laboratory
- Experimental Neurology Group
- Department of Systems Engineering
- Electronic Materials Engineering
- Mount Stromlo and Sliding Springs Observatories

CSIRO:

- Division of Information Technology
- Center for Spatial Information Systems (40 professionals)
- Division of Mathematics and Statistics

The ANU Supercomputing Facility also cooperates with CISR where interests overlap.

CISR is charged with being at the front edge of the advanced computing wave, and through its efforts the CM-2 and AP1000 were obtained. The primary aims of CISR's research program are in the following areas.

- Parallel computing architectures and algorithms
- Artificial intelligence (AI) (neural networks, automated theorem proving and applications of computers to mathematics)
- Information support systems (especially spatial data)
- Human computer interfaces including prosthetics
- Robotics
- Telecommunications
- Large scale scientific computation via vector processors

There are also a number of research relationships between ANU and Fujitsu, Sun, Sequent, Thinking Machines, Esprit, Institute for New Generation Computer Technology (ICOT), and others. The Fujitsu collaboration is the largest and most interesting. Projects being supported under this collaboration include the following.

- Automated reasoning and general reasoning systems
- Software environments for parallel computers
- Design of artificial vision systems
- Extending the software available on VP systems in computational chemistry and computational mathematics

McRobbie also gave me a list of typical research projects associated with parallel computing through CISR at ANU. Many of these are in or have collaborators in the Computer Science Department, but I did not have time to discuss any of them in detail. Readers should contact McRobbie or Stanton for details.

- Parallel Programming Environments
- Integer Factorization Algorithms
- Comparison of Linda and Occam
- Implementation of Linda on AP1000
- Implementation of ML on Sequent
- Unix Utility for Parallel Program Tracing
- Neural Nets for Speech Recognition
- Highly Reactive Systems with Applications to Robotics OS
- Machine Learning in Ecology

- Automated Process and Data Partition for Micros
- Parallelizing the Closure Computation
- Matrix Generator for Implication Connectives
- Artificial Vision
- Parallel Processing in Human Vision
- Receptive Field Analysis in Natural and Artificial Visual Systems
- Electrophysiology of Insect Vision
- Self-Organizing, Syntactic Approach to Gene Sequencing Analysis
- Software for Variance Estimation on Vector Processors
- Program Verification in Modula-2

FUJITSU MACHINES

VP2200

The VP is a "traditional" shared memory supercomputer and placing it in ANUSF means that it will be expected to largely perform a service role. This is a single processor system (model /10) with one scalar unit that will run Fujitsu's UXP/M release of Unix System V, R4. When I was in Canberra the machine was running for users but was still experiencing some minor startup problems. It is commonly accepted that the best performance from a VP series machine occurs when it is configured with two scalar units, so I asked Gingold why ANU did not purchase the second scalar box. He explained that this was entirely a matter of money; the scalar unit is very expensive, as it has roughly the capability of a 3090. My visit was too early to assess the quality of the Unix implementation. But Fujitsu is spending some of its offsets obligations supporting the advanced computing activities at ANU. For this they will get assistance and collaborative research on applications and on Unix development. Two areas in which there are specific collaborations are development of mathematical software for both the VP and AP and computational chemistry. For the latter, work involves benchmarking and analyzing packages and also evaluation of Anchor, a Fujitsu developed pre/post graphics processor specifically designed for computational chemistry. There is also a substantial amount of travel between Japan and Canberra, both associated with the management and operation of the ANUSF and also collaborative exchange visits. [In 1989 and 1990 there were eight exchange visits supported by a Fujitsu grant of $A75,000 ($57,692).] The actual ANU-Fujitsu collaboration is a long term flexible agreement, costing about $A40M ($30.8M) over 5 years, supporting about 40 people, and with a generous partnership in the ownership of intellectual property.

The 2200 is actually an upgrade replacement of a VP100 that was installed in 1988 (this model was manufactured in 1983), so ANU has had several years of experience with VP high-end equipment. Gingold remarked that he had been extremely impressed with the construction quality of the older system and its peripherals, that it had been up 99% of the time (delivering almost 99% of wall-clock time to users), and some peripherals were running even after an astonishing amount of accidental mishandling. The new machine is remarkably cool; air flow out of the CPU box is barely above room temperature. The installed machine has peak performance of about 1 GFLOP, and ANU's very early benchmarks showed matrix multiplication of about 90% of that. This fraction corresponds quite well with the benchmarks I have for the VP2600 and thus appears to be accurate. (A recent report from N. Doduc of Fiat, ndoduc@framentec.fr or doduc@afuu.fr, gave benchmarks for a specific nuclear safety analysis Fortran program on a large number of machines. Doduc explains that this program is only 2% vectorizable, but that in any case its running time on the VP2600 was only about 10% greater than on the Cray C90, e.g., Y-MP16.) The VP100 had a substantial number of well known software packages including NAG, IMSL, ELLPACK, ITPACK, NCAR, and others as well as over a half dozen specifically for chemistry. Presumably these will be continued onto the 2200. The three largest scientific fields using the VP during 1990 were astrophysics, molecular dynamics, and quantum chemistry. ANUSF has a very readable and interesting annual report describing many of the research activities using the VP. This is available by writing to Gingold at the address above.

AP1000

Faculty and staff at ANU were tremendously excited to finally have a really unique parallel computer to work with. The earliest version of this machine was called CAP (Cellular Array Processor), while the current version is essentially equivalent to what was called CAP II. The name was changed by Fujitsu last year because of trademark complications. I have discussed CAP/AP before, but some additional details are presented here.

This is a single-user multiple instruction/multiple data (MIMD) computer (with up to 1,024 processors or cells) that is connected as an input/output (I/O) device (back-end) to a workstation, currently a Sun 4/390, its host. To compute on the AP, a user must write two (or more) programs. One program runs on the host and downloads one or more task programs and data to some or all of the AP's cells.

As is typical of MIMD machines, the cell programs are usually (but need not be) identical and differ only in the data they process and perhaps the program thread (the sequence of instructions actually executed in the cell). Programs are written in C or Fortran, and communication (between cells and between host and cells) is by calls to library routines in host and cell libraries. A subset of Unix runs on the cells and is downloaded into them before program execution begins. At the time I was in Canberra, only C programs had been tested.

There are three separate communication networks, each supported by special hardware. The B-net (broadcast) is 32 bits wide, 50 MB/s, and allows any cell or the host to transmit data to all the cells. (This is used to download programs to the cells.) Behavior of the B-net mimics that of a single shared bus.

The S-net (synchronization) allows cells or the host to test whether all cells are in a particular state and permits efficient barrier synchronization (that is testing to see if all cells have completed a computation before advancing beyond a specific program point). S-net has a tree topology.

The T-net (transmission) allows individual cells to communicate. Each cell has T-net connections to four immediately adjacent neighbors, arranged in a two-dimensional (2D) torus. Connections are 16 bits wide and each has a peak transfer rate of 25 MB/s. Each cell can simultaneously transmit and receive a message. Thus in a 1,024-cell AP, T-net peak bandwidth is 25 GB/s.

Communication between the host and the AP is via a 3-MB/s host-interface (VME bus) into a 32-MB buffer. This link is much too slow for rapid graphics. Fujitsu has promised to do something about this within the next year. Interestingly, an early version of CAP was advertised as a graphics engine and had a distributed frame buffer. This is gone from the AP but perhaps will be added in the future.

Each cell is composed of 16 MB of DRAM (four way interleaved), 128-KB cache (equivalent to 16K double precision words), a 25-MHz SPARC chip designed by Sun, a Weitek floating point unit, various controllers, and network interfaces. Each cell has a peak performance based on the Weitek chip of about 8.33 MFLOPS (single precision) or 5.56 MFLOPS (double precision). Communication is enhanced by a structured buffer pool and wormhole routing.

AP1000 Performance

Although the AP has only been in Canberra for a few months before I arrived, a number of the staff have been using a simulator (CASIM) that runs on a Sun for about a year. In fact, in November 1990 the first joint Fujitsu-ANU CAP Workshop was held at the Fujitsu laboratory in Kawasaki. More than 20 papers were presented, in English. The Australian contributions ranged from software environment issues, debugging, distributed file systems, to implementing BLAS-3, although all these were the result of work only with the simulator. Fujitsu presented details of the AP architecture, as well as a half dozen papers on applications. I have reported on several of the latter before because some had also been presented at parallel processing or high energy physics meetings here in Japan. A least one specific program is given, and this is a good example of the effort required to use the machine. A limited number of copies of the proceedings of this workshop are also available by writing to the Computer Science Department at ANU. Another joint workshop is planned for this November (1991) in Canberra.

At ANU, Brent has done most of the numerical studies of the AP. He commented that he felt the major constraints on performance of the current machine were related to the following.

- Slow host-cell communication (3 MB/s)
- No virtual cells (2D mesh was real)
- High communication overhead for asynchronous data transmission
- Poor optimization from the Sun compilers (instruction set of the cells is identical to that of the host)

He also remarked that communication claims of 25 MB/s have not been realized and that many tests have given consistent results of about 6 MB/s. Both he and M. Osborne noted that at the moment, to effectively program the AP, the user must attend to a great deal of detail related to communications. (One specific software tool that might help is Dino, from researchers in Colorado, and there already has been interest expressed by them in porting Dino to the AP.) Nevertheless, Brent has been convinced that performance within 80% of peak is possible and has devoted a tremendous amount of effort to studying ways of implementing linear algebra on this machine by taking advantage of the hardware.

Table 1 shows preliminary results provided by Brent for his implementation of Gaussian elimination with partial pivoting (which also including checking the size of the residual) on a system of 1,000 equations. In his implementation, he uses "cut and pile" strategy for distributing matrix elements over the cells. In this matrix element a(i,j) is stored in cell (i mod s, j mod t) where there are s times t cells in the AP array. This provides excellent load distribution during elimination but requires some extra work to move the matrix to/from the host.

Table 1. Performance of AP1000 Solving Ax=b With n=1000

Time for One Cell (s)	No. of Cells	Time (s)	Speedup	Efficiency	r_max GFLOP	n_max Order	n_half Order	r_peak GFLOP
161	512	1.10	147	0.29	2.251	25600	2500	2.844
161	256	1.50	108	0.42	1.162	18000	1600	1.422
161	128	2.42	66.5	0.52	0.566	12800	1100	0.711
161	64	3.56	45.2	0.71	0.291	10000	648	0.356
161	32	6.71	24.0	0.75	0.143	7000	520	0.178
161	16	11.7	13.8	0.86				
161	8	22.6	7.12	0.89				
161	4	41.3	3.90	0.97				
161	2	81.4	1.98	0.99				

Brent's program is written in C (with assembler for the kernel of the matrix multiplication). All results are for double-precision (single-precision is about 50% faster). Results were obtained by running at ANU on an AP with 64 physical processors and at Fujitsu Research Laboratories on an AP with 512 processors. To the best of our knowledge, no 1,024-processor machine has been built yet. Brent feels that tuning will improve performance somewhat, but he is already getting more than 290 MFLOPS from a 64-node AP and observes an n_half which is less than an IPSC's. He also feels that his approach could be useful on other similarly organized parallel machines. Brent's results are excellent and will provide Fujitsu with the basis for very efficient software.

Much of the details about the AP were provided to me by

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Remarks

Viewed from the outside, I feel that Fujitsu is extremely fortunate to have such a vigorous collection of researchers at ANU collaborating with them. Similarly, ANU's scientists are fortunate to have two very interesting computers to work on, as there is now worldwide attention focused on their work. It would be much more difficult to generate the same level of awareness had they obtained other equipment even while it might have been easier to run applications (certainly at first). However, for the long run ANU's scientists will have to be alert to keep their research open, objective, and critical and not let it be perceived as favorably slanted toward any vendor. Non-Australian scientists now have a wonderful opportunity to learn about new machines and should make every effort to exploit it.

STRATEGIC RESEARCH FOUNDATION (SRF)

In 1988 the State of Victoria set up, in Melbourne, SRF with a $A30M ($23.1M) *allocation* through 1993 to focus scientific research in economically profitable directions via collaborative research and related seeding activities and by developing appropriate policies for encouraging and managing research. With the help of various working groups and a Board of Directors, SRF has considered a number of technology areas. For some of these specific actions have occurred. The process is considered open ended. (Also see my comments about SRF in an earlier section of this report.) Examined areas are as follows.

Advanced Computing

The Australian Computing and Communications Institute (ACCI) was founded in December 1990 with a startup budget of about $A40M ($30.8M), jointly funded by the Government, IBM, Siemens, and Computer Power Group, and a plan to have 40-60 staff, mostly in research. (DEC has not contributed any money but has an observer on the

Board.) Five research institutes are also involved: the University of Melbourne (Dept of Computer Science), Monash University (Dept of Electrical and Computer Systems Engineering), the Royal Melbourne Institute of Technology (Dept of Computer Science), the Australian AI Institute, and CSIRO (Division of IT). An IBM 3090-400J has been installed and at least 25 IBM RS6000 workstations are going in. By July 1993 the 3090 will be replaced by an ES9000/620, and there is the possibility of an ES9000/820 if ACCI is financially sound. The 3090 is physically located at the University of Melbourne, and optical fiber links are either in place or going in between various participants. Organizationally, the 3090 is at the Advanced Computing Techniques Laboratory (ACTL), although it remains part of ACCI.

ACCI is focusing its activities on three main areas.

- Intelligent decision systems
  - Intelligent control (real time reasoning systems, decision-techniques, deliberation strategies, distributed real-time reasoning systems) for applications in the Civil Aviation Authority (CAA), the National Aeronautics and Space Administration (NASA) (U.S.), and Telecom.
  - Planning and scheduling (combining constraint satisfaction methods from math programming with AI techniques such as tree searching) for application in the CAA and Defense Department.
  - Dynamical object recognition (surface recognition, three-dimensional perspectives, prediction of geometric and material properties, encoding and recovering features in large databases) for application in factory production, satellite feature identification, x-ray magnetic resonance image understanding.
- Communication technologies
  - Coding techniques with applications to video-telephone and video-conferencing.
  - Network signalling, switching, control for applications via ISDN, B-ISDN, FASTPAC.
- Visualization technologies and human computer interface
  - Development of software for generating images from large data sets, specifically for weather and climate modeling, mineral exploration, and financial models.

Advanced Materials

This is still in the evaluation stage, but the main focus will likely be in the following areas:

- Optoelectronics for computer architectures, fiber-based communications, sensing and control devices, and consumer electronics
- Blended polymers
- Ceramics and ceramic composites
- Materials characterization

Climate and Ocean Sciences

This is still in the evaluation stage. The potential focus is on (1) computing aspects of climate prediction and (2) physical and chemical phenomena (rather than biology) such as pollution dispersion, marine structure design, shipping, remote sensing, and image processing technology.

Agricultural Biotechnology

A Plant Biotechnology Institute is being established with a planned staff of about 30.

Biomolecular Research

A Biomolecular Research Institute (BRI) was formed with the goal of becoming a world-class research institution, producing information for the design of new pharmaceuticals and biological control products. Tools will include x-ray diffraction, advanced computing, nuclear magnetic resonance (NMR) spectroscopy, electron microscopy, diffraction, and mass spectrometry. The Convex C210 was purchased for this institute. BRI will have about 40 staff members and 20 Ph.D. students. Its budget will be around $A20M ($15.4M).

Energy and Mineral Resources

This is still in the evaluation stage. The potential focus will be on (1) advanced exploration techniques and equipment, (2) use of brown coal as reductant, (3) novel uses of natural gas, and (4) development of solid (ceramic) fuel cells.

Other Areas

- Pulp, paper and forest products
- Very early studies of image acquisition, analysis, and display

For information about SRF contact

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COLLABORATIVE INFORMATION TECHNOLOGY RESEARCH INSTITUTE (CITRI)

As I mentioned earlier, there is plenty of controversy about the Strategic Research Foundation and ACCI in particular. This especially concerns its relationship with all the local Melbourne universities and the University of Melbourne in particular. The University of Melbourne, the Royal Melbourne Institute of Technology (RMIT), and the State of Victoria have set up an organization (Collaborative Information Technology Research Institute, CITRI) that is roughly similar to ACCI. The founding organizations have injected about $A16M ($12.3M) to get CITRI going, and further federal funding of over $A10M ($7.7M) over 5 years has also been obtained.

CITRI claims four main areas of expertise, based on researchers associated with the universities.

- Vision and Graphics--Signal processing, computer vision, pattern recognition, interactive imaging, geometric modeling, graphics for printing and TV.

- High Performance Computing--Computer architecture, operating systems, parallel computing.

- Intelligent Decision and Control Systems--Database management, deductive databases, logic programming, VLSI design, operating systems.

- Communications and Signal Processing--Telecommunications networks, CCITT language, high-speed optoelectronic devices, integrated photonics, multi-gigabit optical links.

For information about CITRI, contact

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General Manager
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or

Prof. Ron Sachs-Davis
Research Director
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For outsiders, the simplest thing to say is that computing technology in Victoria is moving forward, but which organization is going to be pivotal is best left to the Australians to work out.

BRIEF COMMENTS ON SITE VISITS

I spent 1 day at several rushed visits to Queensland University of Technology, the Center for Information Technology Research at the University of Queensland, and Griffith University. The descriptions below are very brief and are based on my conversations with Mohay, Cook, and Pritchard.

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Queensland University of Technology (QUT)

QUT is a new, urban university formed from an Institute of Technology in 1989. There are about 12,000 students and a new Ph.D. program in computer science built around a faculty of 25, as well as another 25 faculty in information science, both within the Faculty of Information Technology. There is very little numerical computation, but there are several transputer systems, a Convex, and a proposal for a 128-processing element (PE) Meiko Computing Surface in collaboration with the School of Computing and Information Technology (CIT) at Griffith University and the Mathematics Department at the University of Queensland (see below).

To my surprise there is a very active

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Australia
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Fax: +61-7-221-2384
Email: w.caelli@qut.edu.au

There are nine faculty members associated with the center, mostly part time. Its major activities are in (each of the groups below has three to eight researchers):

- Cryptology (key collisions in data encryption standard, statistical analysis of block and stream ciphers).

- Risk analysis and assessment (methodologies, automated assessment of vulnerability of key management protocols).

- Electronic data interchange/open systems interconnection (EDI/OSE) security (security management information base).

- Database (DB) security [formal specification of DB transactions and operations, sensitive DBs in insecure operating systems (OS) and database management systems (DBMS)].

- Access control and secure operating systems.

- Viruses and PC security (assessment of viruses).

The center is both a research and educational center, with diploma (B.S.) as well as M.S. and Ph.D. courses. There is also a significant industrial partnership, and center literature lists various clients and projects. The director, Caelli, is the founder of Eracom, a company that manufactures cryptographic equipment for the banking industry.

Center for Information Technology Research (CITR)

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Research (CITR)
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CITR is an independent, for profit, center within the University of Queensland that is almost 5 five years old. It was established with a seed grant of $A600,000 ($461,539) in 1986. It is now self-funding and profitable and supports its staff of 26 (principally R&D engineers, 7 with Ph.D. degrees) with its revenue, as well as another 9-10 faculty members at the university. In 1990 its revenue was about $A2.1M ($1.6M) and it had a profit of $A264,000 ($203,077). It is working in four major areas:

- Distributed information systems (distributed database and information systems).

- Smart communications (OSI, X.400, X.500, EDI, B-ISDN, performance analysis).

- Software engineering (expert systems, formal methods, CASE tools, Unix system applications).

- Microelectronics (ASICs, custom VLSI, integrated circuit (IC) design methodologies, computer-aided design (CAD) software tools).

Griffith University

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Griffith University is a 14,000-student university outside the City of Brisbane, with a new information technology (IT) school composed of about two dozen faculty, mostly newly recruited. The State of Queensland has established a Software Quality Institute at the university that will perform research, consult and cooperate with industry, and provide various degree professional development courses. Both the IT school and this institute are going through the usual birth process.

AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANIZATION (ANSTO)

This is the country's governmental nuclear science and technology (S&T) organization. It is responsible for all aspects of nuclear science and related activities, including applied research, commercialization, training, etc. It is the governmental arm responsible for supporting national/international policies and interests. ANSTO has a staff of 800 with a budget allocation of $A60M ($46.2M). ANSTO's main facility is located in suburban Sydney; its major programs are as follows:

- Advanced Materials. A main project focuses on the development of "Synroc," a ceramic matrix for high level radioactive waste immobilization. This synthetic rock is analogous to natural materials that are known to retain their original content of radioactive elements for millions of years. A demonstration plant has been built at ANSTO. (On this project there is collaboration between Australia, the United Kingdom, Italy, and Japan.) Other projects include ceramic superconductors, biomedical piezoelectric and ultra-high strength ceramics, high-energy density capacitors, plasma processing of materials, and remnant life assessment of engineering components in industrial plants.

- Applied Physics. Installation of tandem accelerator for research on mass spectrometry, neutron radiography, laser enrichment technology, radiation detection and standards, sources, instrumentation, etc.

- Environmental Science. Environmental impact associated with mining of uranium and related ores, transport processes, biological uptake, groundwater and atmospheric uptake modeling, chemistry of waters, etc.

- Industrial Technology. Quality assurance, total quality control, safety and reliability assessments, etc., mostly related to isotopes, radiation, radiochemistry.

- Biomedicine. Nuclear applications, radiation biology, radiopharmacology, radiochemistry, modeling, etc. ANSTO also owns and operates a cyclotron in conjunction with the Royal Prince Alfred Hospital.

- Nuclear Technology. Neutronics and thermal engineering and operation of two research reactors. The large one, HIFAR, produces radioisotopes for medicine and industry, and these are sold commercially, generating a substantial amount of revenue.

There has been a significant change in ANSTO and other Australian Government research facilities in that by 1993 they must generate 30% of their funding from outside sources. This has permeated all aspects of the organization's activities. One effort in this direction is the decision to set up Australian Supercomputing Technology (AST), a joint venture between ANSTO (70%) and Fujitsu (30%). The Japanese company will invest $A18M ($13.9M) over 5 years. The heart of the project is the installation of a VP2200, configured similarly to the one at ANU, except that (at first) it will run a slightly older version of Fujitsu's Unix. AST is planning to develop engineering application software and sell service, not time, on this machine. When I visited, AST had just moved into a new building (telephones had just been installed); the VP had just arrived and was undergoing acceptance testing. My contact at ANSTO was

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Barry is an applied mathematician who has worked with Gene Wachpress in the area of reactor modeling. One of his recent activities has been to run workshops on the use of supercomputing for Australian scientists.

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION (CSIRO)

CSIRO is Australia's largest scientific research organization, with a staff of 7,200 including 2,500 scientists and engineers, working in laboratories all over the country. Recently CSIRO went through a lengthy priority setting exercise, and its entire structure has been changed to make the pieces function in a more coordinated way and to make sure that the research has some direction and applicability. As with other governmental facilities, CSIRO is hoping to bring in 30% of its funding from external sources by 1993 and has worked out details of various possible partnerships and other commercial arrangements. CSIRO is definitely "marketing" its activities, with slick newsletters, classy annual reports describing earnings from the operating units, press releases, calendars, etc., as well as the usual collections of technical reports. Every piece of literature I picked up stresses "increase competitiveness of Australian industry," "give strong economic benefit to the nation," etc. Interested scientists will get a mailbox full of information by contacting

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The new CSIRO structure groups everyone into one of six institutes, which are further subdivided into divisions. Actual operations are widely distributed. For example, the Division of Mathematics and Statistics has regional offices in Sydney, Melbourne, Canberra, Adelaide, and Perth. Further distribution occurs because many university faculty members have significant research collaborations with CSIRO scientists and because some CSIRO sites are essentially on university campuses. CSIRO also operates the Australia Telescope and the oceanographic research vessel *RV Franklin*. Below I have listed the institutes and divisions. For each institute I have given its percentage of operating funds. I visited scientists at the two marked CSIRO divisions, and more details about these are given below this list.

Information Science and Engineering (6.8%)

Information Technology (visited)
Mathematics and Statistics (visited)
Radiophysics
Space Science and Applications

Industrial Technologies (17.2%)

Applied Physics
Biotechnology
Chemicals and Polymers
Manufacturing Technology
Materials

Natural Resources and Environment (15.3%)

Atmospheric Research
Fisheries
Oceanography
Water
Wildlife and Ecology
Environmental Mechanics

Minerals, Energy and Construction 17.1%)

Building, Construction, Engineering
Exploration Geoscience
Geomechanics
Mineral and Process Engineering
Mineral Products
Coal
Fuel

Animal Production and Processing (20%)

Animal Health
Animal Production
Tropical Animal Production
Food Processing
Human Nutrition
Wool

Plant Production and Processing (23.6%)

Entomology
Forestry
Horticulture
Plants
Tropical Crops and Pastures
Soil

The Institute of Information Science and Engineering was of greatest interest to me, as it houses most of the directly supported computing and math activity. Its total budget is about $A40M ($30.8M), with a staff of around 450. The two largest groups are Radiophysics and Australian Telescope, accounting for about 60% of the staff and almost half the budget. Some details of two specific divisions are given below. A general contact for the institute is

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Institute of Information Science and Engineering

Division of Mathematics and Statistics. This division has a staff of about 90 and a $A5M ($3.9M) budget. The division's expertise is in mathematical and statistical modeling, quality and process improvement, statistical experimentation, computational fluids, signal and image analysis, large datasets, graphics, mathematical/statistical computing environments, and operations research. Its main location, outside Melbourne near Monash University, means that the division has active contact with this university's staff. My host here was

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Western scientists know quite a bit about the work of selected scientists at DMS such as Frank de Hoog, Paul Cleary, Nick Stokes, and perhaps others. Frank de Hoog, for example, won the 1988 Medal of the Australian Mathematical Society for his work in numerical solution of differential and integral equations. A number of papers from this division were presented at the International Conference on Computational Techniques and Applications (CTAC'91) in Adelaide (below). One described modeling of the sound generated by the blades of industrial fans in an effort to minimize this kind of noise, while another modelled flow of granular materials during grinding or crushing operations. Another interesting project is the development of a smart battery tester, a floating point microprocessor that can assess the quality of a car battery at an arbitrary state of charge and temperature.

Within the division, four groups have their individual focus:

- Applied Math: CFD and related physical modeling.
- Statistics: Quality/process improvement, wear assessment, modeling of industrial processes, computer-intensive statistical methods, fission track analysis.
- Signal-Image Analysis: Multispectral remote sensing, analysis of high dimensional data, image analysis of microstructure, signal detection, software for image analysis.
- Software and Networks: Enhancements to "S" (well-known statistical environment from Bell Labs), networking, and X-Windows support.

Division of Information Technology (DIT). This division, with a staff of 80 and a $A6M ($4.6M) budget, is colocated in Melbourne, Sydney, and on the ANU campus in Canberra. In Canberra, my host was

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In Melbourne I visited a number of people, including

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and

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as well as Dr. Rhys Francis (Email: rhys@mel.dit.csiro.au).

The division has three main programs and each has several subprojects:

- High Performance Computing and Communications (Melbourne)
  - Open Communication
  - High Performance Computation
- Knowledge-Based Systems (Sydney)
  - Knowledge Modeling
  - Knowledge Systems Engineering
  - Knowledge & Information Navigation
- Spatial Information Systems (Canberra)
  - Systems Design & Development
  - Visualization Systems
  - Geographic Information Systems
  - Decision Support Systems

Queries about projects should be addressed to the laboratory managers at these sites: Abramson in Melbourne, Dr. Peter Fox in Canberra, and Dr. Bob Jansen in Sydney.

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High Performance Computing. I describe some aspects of the High Performance Computing project in the context of a paper presented at CTAC'91 in Adelaide. For me, the interesting thing is that the research is application driven. The CTAC'91 paper discusses a special-purpose weather modeling language being developed for fast prototyping and development of climate modeling schemes on a variety of parallel and vector computers. The group is also looking at architectural aspects of climate and weather modeling applications (what machine architectures suit this type of computation) and has tried a number of different parallel machines against the dynamics of weather models.

Several other applications are also being studied. One is the development of a special-purpose architecture for implementation of simulated annealing for discrete event scheduling problems. This is a board for a PC which I was told provides a 50-fold performance improvement over a Cray Y/MP (but no floating point; these are purely combinatoric computations). This is now at the stage of commercializing an implementation for school timetable construction, which is done by applying simulated annealing to minimize a cost function associated with the number of clashes in any given timetable.

Another application is to biomolecular computing, with the division staff studying whether special-purpose hardware or a commercial multiprocessor will be best for running the drug-design software, X-Plor. They have run versions of the package on a Vax 8800, Cray X-MP, Y-MP, a Convex C-1, a Sparc 4/65, and on the Encore Multimax and have been looking at the Schedule package (Dongarra, Sorenson) for process forking.

A final project is to parallelize an existing computer system simulation kernel and compare Chandy-Misra with time warp simulation methods. For the past few years the High Performance group has also been studying dataflow, but that research has mostly finished now. The group did not find anything commercially viable in an Australian context, although Abramson mentioned that in Japan Prof. Terada (Osaka University) had recently build a dataflow chip with the support of several Japanese companies, and he also mentioned work at the Japanese Electrotechnical Laboratory (ETL) that we have reported on several times during the past year.

In the Open Communication project group, I only had a brief opportunity to meet with Dr. Trevor Hales, its project manager. Project literature notes that the goals of the group are to develop applications using the communications standards provided by the OSI protocols produced by CCITT and ISO. Current areas are ISODE (software implementation of OSI standards), PP enhancements (an implementation of the X.400 standard), Directory User Agents (DUAs) for interrogation of databases (this is associated with the X.500 standard), and developing a distributed meetings organizer using the ANSA distributed workbench.

The Supercomputing Support group (R. Bell) is part of DIT and is responsible for assisting CSIRO users in supercomputing as well as developing a CSIRO-wide supercomputing policy and strategic plan.

After I left Australia, Abramson wrote to mention the cooperative research center, the Center for Intelligent Decision Systems (CIDS). This is concerned with R&D in intelligent decision support systems, including planning and scheduling, real-time control, advanced database, vision, and spatial planning systems. The participants include the Australian Artificial Intelligence Institute (AAII), the University of Melbourne, RMIT, CSIRO, and the Aeronautical Research Laboratories (ARL) of the Defense Department. The center director is Dr. Michael Georgeff of AAII (georgeff@aaii.oz.au). Abramson's group is collaborating with these researchers in applying parallel computing to such intelligent systems, in particular, in computationally expensive scheduling and planning systems.

Knowledge-Based Systems. Until recently the basic emphasis here was in knowledge processing (hardware and software), in particular, in associative memory techniques. In 1988 the group built a high-speed table search processor (Relational Algebra Accelerator, RAA) jointly with the University of New South Wales. There has also been research in Persistent Prolog, tools to help construct and maintain rule-based expert systems (especially maintenance of systems evolved through extended use), and a knowledge dictionary for hypertext and hypermedia. Finally there has also been work on evolving the methodology of the entity relationship attribute approach to encompass Jackson's CSP approach. Various prototypes have been built.

The emphasis is now on the development of knowledge acquisition, representation, and navigation (hypermedia) techniques and on the integration of these into hypermedia advisory systems, e.g., for complex documentation, technical publications, and government legislation. A Hyperbook product (*Knowledge Dictionary*) based on Bob Jansen's thesis will be published by Academic Press next year. Research on knowledge acquisition is largely based on John Debenham's work on knowledge systems engineering (see his book on this subject). (Debenham is at the University of Technology Sydney (UTS), newly upgraded and renamed from the New South Wales Institute of Technology, and working part-time with DIT). Recently, a Center for Advanced Systems Engineering has been established between CSIRO and Macquarie University, and the division will be contributing to projects in this center.

Spatial Information Systems. The basic interests in this group are spatial databases, spatial inferencing, image processing, spatial analysis and mapping, advanced graphics, and related distributed computing. This group uses a Maspar MP-1 with 1,024 processors for much of their research. A very well written paper on the group's experiences using it to render perspectives of terrain surfaces was presented at Computer Graphics International '91, in Boston. There are a number of interesting projects and actual products that are associated with the group.

The Interactive Territory Assignment (ITA) addresses location-allocation problems. There are various options to address criteria such as efficiency in terms of transportation cost, compactness of territory shape, restrictions on size and connectivity, etc. ITA is being used by a Victorian bank to study branch locations and by the Australian Electoral Commission for redistricting proposals. I was particularly interested in this, as it has many similarities with software developed at the National Institute of Standards and Technology (NIST) for Internal Revenue Service (IRS) locating.

GAIA is a terrain modeling/analysis system that develops regular grid elevation models and incorporates drainage, allowing applications where water flow is important. This is being used by the Department of Forestry and the Australian Surveying and Land Information Group.

One of the larger projects is the development of DISIMP (Device Independent Software for Image Processing), specifically designed for analysis of remotely sensed data, including multispectral images from Landsat, Spot, and the National Oceanic and Atmospheric Administration (NOAA) satellites, which allow integration of these images with related topographic, geophysical, and cultural data. There are over 50 DISIMP sites worldwide and the software is being distributed by Sun, but it also runs on a number of other vendor's workstations.

The Visualization group has been studying the demands on hardware and software by realistic problems. Robertson made it clear to me that he feels the emergence of inexpensive parallel systems (especially single instruction/multiple data (SIMD) systems), along with increased display-processor bandwidths and large memories, will be able to support interactive displays on modest cost systems. What is still needed is appropriate software, such as user interface, display design and construction, and integration of parallel algorithms. In particular, he believes that much more work needs to be done on methodologies for interactive display design, and some type of information theory for visualization is badly required. I agree.

Remarks. I was extremely impressed with the scope of activities in this division. They have excellent links with scientists outside of Australia. In the area of parallel computation, Abramson and his colleagues are very well informed. He is one of the organizers of a conference on "High Performance Special Purpose Architectures (HICSS)" to be held 7-10 January 1992 in Kauai, Hawaii, and is one of the co-chairs of the 1992 ACM International Symposium on Computer Architecture to be held on the Gold Coast in May 1992. (Also in May 1992 there will be the International Conference on Software Engineering, to be held in Melbourne; the General Chair is A.Y. Montgomery from the Royal Melbourne Institute of Technology, aym@goanna.cs.rmit.oz.au.) Abramson has also compiled a directory of parallel processing projects in Australia. Both the High Performance and the Visualization groups have written a large number of papers; almost all have been published in easily obtained journals or conference proceedings from ACM, IEEE, etc., so I will not list these here. Interested readers should contact either Robertson or Abramson directly at the addresses above.

The division is a member of the Australian Software Foundation (ASF), a common interest user group formed to promote the industrialization of software development. The foundation has the support of the Government and the major industry association in Australia. In December 1990, ASF and its European counterpart ESF signed a memorandum of understanding (MOU). ESF has generated over $500M in funding over 10 years. There is also an MOU with the Eureka Software Factory to collaborate on the development and promotion of the Software Factory concept. The division's chief (John O'Callaghan) has been actively involved in ASF and with developing international links in the area of software engineering and IT in general. He has been responsible within ASF for coordinating German-Australian workshops on object-oriented approaches to software engineering with GMD--the first was held in January 1991; the second will be in November 91. Funding for these workshops comes under the Australia-Germany S&T Agreement.

INTERNATIONAL CONFERENCE ON COMPUTATIONAL TECHNIQUES AND APPLICATIONS

The International Conference on Computational Techniques and Applications (CTAC'91) was held in Adelaide, South Australia, on 15-17 July 1991. The University of Adelaide is adjacent to the University of South Australia. Both shared the responsibilities of managing this meeting. The general chair was

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Noye was also the author/coauthor of four contributed papers. The conference director was

Prof. B.R. Benjamin
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Immediately following the conference, a 1-day supercomputing workshop was held by Dr. Jerard Barry, Australian Nuclear Science and Technology Agency, to initiate scientists about the issues of vectorization and algorithm restructuring.

The conference consisted of six invited addresses and about 50 contributed half-hour lectures in two parallel sessions. The invited addresses were the following:

- "Computational Mechanics," Marc Cross (Thames Polytechnic)
- "Applications of Supercomputers," Graham Carey (University of Texas, Austin)
- "Symbolic Computing, Automatic Programming and Literate Programming," Bart Childs (Texas A&M University)
- "Parallel Matrix Decomposition, Algorithms for Separable Elliptic BVP," Graeme Fairweather (University of Kentucky)
- "Exploiting Parallelism in the Solution of Multipoint BVP," Mike Osborne (Australian National University)
- "Finite Element Methods for Complicated Laminar Flows," Nick Stokes (CSIRO)

There were between 100 and 150 attendees; all but one or two were Australian. This was surprising to me, as the meeting was well advertised internationally and would have been a valuable way of learning about the excellent work "down under." CTAC reminded me of earlier, and much smaller, SIAM conferences in the United States. The atmosphere was very academic, there were no vendors or other exhibits, and everybody seemed to know everybody else. Several Japanese conferences in computational mathematics have had this same flavor.

The contributed papers, with a few notable exceptions, focused on the analysis of physical systems, notably weather, ocean flows and tides, and various simulations associated with the huge mineral industry, such as flows inside a gas cyclone, extrusion and solidification in aluminum processing, granular flows, well bores, etc. The emphasis was on analysis, rather than computation, but several supercomputer computations were shown. Some were done in Australia, others at collaborator's institutions. Two interesting collaborations were (1) a paper on simulating sedimentation via molecular dynamics by scientists from the Materials Research Laboratory of the Australian Defense Science and Technology Organization and the Materials Division of the U.S. Naval Research Laboratory (NRL) in Washington, DC, using a Cray X-MP; and (2) a paper modeling detonation in homogeneous materials, also by DSTO's Materials Research Laboratory, and the Aerospace Engineering Department of the University of Michigan and the Computational Physics Laboratory, again at NRL, this time using a Cray Y-MP at a service bureau in Australia.

Another good example of the type of modeling that typifies Australian flow research is the work of A. Stokes (CSIRO). This includes finite difference, discrete vortex, spectral approaches, and finite element approaches. For the latter they have been focusing on simplex geometry and automatic mesh generation.

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Many of the speakers distributed copies of their papers to the conference attendees. A proceedings will also be available from the meeting organizers, but not for several months. Because the papers are all in English and very accessible I will not review many in detail, but instead I will describe a few that were of particular interest to me (I omit discussion of any papers entirely by U.S. authors.)

One of the most advanced projects, in terms of applications, was presented by R. Francis, D. Abramson, and M. Dix (CSIRO), a collaboration between the Information Technology and Atmospheric Research Divisions. They are looking at good ways to build large (and extremely complex) weather prediction programs and how these programs can most readily adapt to the increasing number and diversity of parallel processing environments that are becoming available. Their base program is a 20,000-line Fortran 77 program, a nine layer (9 x 64 x 56) climate model. They have developed a new spec language (DWARF) and a separate code generation system that is tailored for several existing shared memory distributed memory machines. Of course, the goal is not only to allow rapid prototyping but also efficient code generation. Because DWARF is more specific than a general parallel language, they feel it will be easier and faster to retarget to a new machine than with a conventional compiler. Several examples were presented, related mostly to the shallow water equations. The authors freely admit that many researchers are studying automatic, or semiautomatic, parallelism. But I like this approach because it is closely tied to a specific application domain; many people believe that too much generality cannot permit really efficient code development. For information, contact Dr. David Abramson (see the section on CSIRO for his complete address).

Grant Keady (University of Western Australia) gave a lecture surveying software tools for generating Fortran or C from computer algebra (CA) systems, typically Reduce or Macsyma, but also other systems such as Mathematica. CA systems have had their greatest use when there is some "algebra" to be done. Keady's interest has been associated with Jacobian code production for various optimization algorithms. One can use CAs to generate Fortran or C, but it is usually better to make use of one of several higher level systems (called a GenTran, for Generation and Translation) that hides many of the details. Some of these GenTrans have been focused on the Nag library (particularly those developed in Europe). I had not realized that so much work has already been done in this area. Details of a workshop on symbolic computing and applied math were presented in the *SigSam Bulletin*, July 1991. Another workshop to be held on 23 October 1991 (Environments for Numerical and Algebraic Computation) at the University of London Computing Center will focus on Senac from the University of Waikato (New Zealand). In mid-July 1992, there will also be a workshop on Maple in teaching of mathematics, to be held in Perth after a week containing three other mathematics meetings (Australian Mathematics Society, Australian Statistics Society, Combinatorial Mathematics & Combinatorial Computing). At the Auckland, New Zealand, Scientific Computation and Differential Equations meeting (January 1993) there will be some demonstrations of GenTrans associated with control theory packages. The vigorous level of research on this topic in Australia and New Zealand has not made itself felt significantly in the United States. For example, a meeting in Purdue at the end of

1988 (IMACS/IFAC International Conference on Expert Systems for Numerical Computing) had no participants from either of these countries. Perhaps the connection to the United Kingdom is more natural than to the United States, but it is time that U.S. scientists made themselves better aware of the efforts here. For information contact

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M. Lukic (Phillip Institute of Technology) discussed extensions of the Bohlender method for the maximum accuracy summation of n floating point numbers. Its main differences are that it uses a single length mantissa to obtain a single precision result, it can compute the sum to any prescribed accuracy, and it does not use upward or downward roundings.

P. Cleary (CSIRO) discussed numerical techniques for granular flows. These are the bulk movement of independently moving solid particles and are significant components of landslides, planetary rings, slurries, silos, chutes, etc. The particles have a large amount of interparticle friction as well as a high coefficient of restitution. Current numerical methods for modeling such systems follow the exact trajectories of all the particles. As the particles move from one time step to the next, small (but obviously nonphysical) overlaps are produced. Each time an overlap is noted a collision mechanism is applied. There are two general approaches. In hard collisions, each overlapping pair is viewed as undergoing an independent binary collision. In soft collisions, the force produced by each collision is modeled by a spring and dashpot in the normal direction and spring and surface friction in the tangential direction. Cleary's work involves studies of the differences between these methods and various hybridizations of them. He also showed a very well made computer video displaying several different situations.

P. Howlett, P. Pudney, and B. Benjamin (University of South Australia) gave a paper (also studied by other authors) concerning determination of optimal control strategies for train control in hilly terrain. The goal is to meet given schedules with minimum fuel. The analysis has actually been applied to the development of an onboard computer (Metromiser), which is being installed on long distance Australian trains. The authors claim that 15-20% fuel savings are realized.

There were three papers discussing experiences developing programs for advanced computers. A traditional approach of moving from a Vax 11/785 to a SPARCstation and then to a Cray Y-MP for a three-dimensional tidal model (plus wind-induced circulation) was described by J. Nixon (University of Adelaide). This paper is more like a diary of what happened, but it was very clearly written and addresses the issues of vectorization directly. Scientists from BHP Research Laboratories in Newcastle considered a specific pressure correction algorithm (Simple) in widespread use for solving a version of the Navier-Stokes equations. Their paper analyzes the performance of two parallelizing approaches, one using a Silicon Graphics 8-CPU shared memory multiprocessor and the other using a set of nine T800 transputers (housed in a PC). Of course, the second case required much more effort to port. Overall, the authors note that the transputer system implementation "achieved lower performance and efficiency than the shared memory implementation, though on a considerably lower cost hardware platform."

Finally, a paper by D. Singleton (Australian National University) and G. Meyer (Georgia Tech) described a parallel implementation of a Method of Lines (MOL) for solving free boundary problems on the Connection Machine. In the MOL, partial differential equations are converted to a system of ordinary differential equations (ODE) by discretizing all but one of the variables. Usually time is left continuous. This is a very common approach and one that has been enhanced by the availability of excellent ODE solvers. The current authors' approach has been to assign a line (one spatial point) to each processor, and hence solve the ODE along each line in the memory of the local processor. There is very little interprocessor communication. The ODE implementation is simple trapezoidal rule, with small steps near the physical boundary. Adaptive ODE solvers are ruled out here because the hardware requires that a uniform step must be applied on all the lines, although the authors admit that better integrators would help with some other technical problems. To find the free boundary it is necessary to do some root finding. This is a capability that is common to ODE software, but the SIMD implementation requires some novel twists. There are only a few timing results. The computations were done on the 16K CM at ANU. (This machine has not been up for very long and is still underutilized, perhaps 50% according to Singleton.) The authors note that the speed-ups they obtained were very reasonable, but that "the CM performance only becomes impressive when it is being fully utilized on large problems." They also noted that while it was easy to get their code up and running on the CM, this will not generate really good performance. For that it was necessary to use lower level tools than those available via Fortran.

There were several papers on "pure" numerical analysis, which is tied only very loosely to applications. These cluded papers on singular value :composition (SVD) for Toeplitz atrices (D. Sweet), the Jacobi matrix elated to orthogonal polynomials) . Elhay), equidistant-node polynomial terpolation (Mills and Smith), differential equation eigenvalue bounds, ıd approximations of algebraic func- ɔns (McInnes).

M. Osborne (Australian National niversity), in joint work with ri Ascher, gave a very elegant paper lated to looking for ways to utilize ırallelism in the solution of boundary ılue problems for ordinary differential ıuations. After discretization, the ılution of a structured system of linear ıuations is required. Since the equa- ons are block bidiagonal, the method f cyclic reduction can be applied. ısborne considers extensions of the :chnique to overdetermined multipoint roblems and also to Kalman filters, as ell as to issues of parallelization. Like ther numerical analysts he believes ıat thinking parallel can have general enefits.

K. George (Email: karen@echo. ınberra.edu.au), who is a Ph.D. student f Osborne's, gave an interesting ımmary of her research in minimizing olyhedral convex functions. She claims ıat these results will have significant pplication in the solution of linear rogramming (LP) problems and are ɔmpetitive or better than existing lgorithms.

IESEARCH ACTIVITIES ꟷ SOUTH AUSTRALIA

The State of South Australia was ne of the hardest hit by the recent conomic downturn. As in all the other :gions of the country, the local gov- rnment is trying to find ways of gener- ting new business. South Australia as three major universities (Univer- ty of South Australia, University of ıdelaide, and Flinders University) and ther research institutes. Two activi- es are of particular interest.

Adelaide Technology Park and MFP

Several years ago MITI approached the Australian Government with some suggestions about a large-scale development project--essentially a city of the future--where living and working would be combined harmoniously. The ideas got to the stage where a competition was held to determine what part of Australia would be the best site. The provisional winner was the State of Queensland, in the northeast corner of the island with Brisbane as its major city. But a controversy about the specific site ensued and the area was disqualified, to be replaced by a site immediately outside Adelaide (which is on the south coast). The Adelaide project was named "Multi Function Polis." This must have sounded more like a malady than a solution, so recent literature refers to it only as MFP. (Now it simply sounds like a toothpaste additive to me.) There is still plenty of controversy. The Adelaide and South Australia Governments want MFP to be viewed as a national project (with appropriate resources made available), although most of the immediate benefits will be concentrated locally. There are environmental questions about the site, concerns about displacement of (mostly working class) families to be replaced by professionals, and some under-the-surface racial worries about Japanese enclaves. The debate is spirited, but healthy. There is still a great deal of Japanese interest, but it is not being emphasized.

For the purposes of this report, MFP is interesting because it is focusing on using technology to help people live and work more easily. Information and telecommunications capabilities are at the heart of the project, and 21st century solutions are proposed for housing, energy, water, waste, traffic, surroundings, etc. It is hoped that an "information utility" will include various computer networking options as well as large-scale general computing services (at the moment there are no supercomputers in this part of Australia), that it will become a key site for the location of software and services for the entire Asia-Pacific region, and that especially in the area of software it will become an internationally recognized research and engineering center, via an Advanced Information Technology and Telecommunications Education Facility, an Australian Software Foundation, and a Software Conversion and Development Factory.

The existing universities are part of the strategy, as is the development of a new MFP university. Several laboratories associated with the Government's Defense Science and Technology Organization (2,700 staff) are nearby (Surveillance Research Laboratory, Electronics Research Laboratory, Weapons Systems Research Laboratory, Aeronautical Research Laboratory) as are various institutes such as the Center for GaAs VLSI Technology, Electronic Structure of Material Center, and others. Adelaide has Australia's highest concentration of microelectronics expertise, electro-optical instrumentation sensing, and defense electronics. There is also a high level of expertise in metal-bending, sheetmetal, plastics, and reaction injection molding. These are all to be integrated into MFP. There is already a technology park (the first one in Australia) with more than 50 R&D corporations and a developing science park in a slightly different location. At the moment all the companies sited there are Australian, including Sola, which is the world's largest producer of ophthalmic resin lenses. It is hoped that international companies, especially Japanese, are waiting in the wings. Of course, there are many other ideas that are being discussed, but it is also only fair to state that at the moment the most concrete items are a plot plan, artists sketches, and literature. Nevertheless, for Western scientists, the combination of English language and culture and Asian locale could make this a very attractive opportunity.

Signal Processing Research Institute (SPRI) (Adelaide)

This is an attempt to capture the expertise of the Defense Science and Technology Organization, the three major South Australia universities, and various local defense, electronics, and space companies and to focus their research in communications and signal processing. Outside of the United States and EC, this is the largest concentration of digital signal processing (DSP) expertise anywhere. There are four major suborganizations in SPRI.

- Institute for Computer Systems Engineering and Assurance
    - Software project management
    - Software engineering (object-oriented methods, user interfaces, environments, safety critical software, quality assurance procedures)
    - Databases (object oriented and temporal)
    - Distributed systems
    - Ada
    - Knowledge-based support systems

(A great deal of the initial support for this group came from DEC.)

- Australian Space Center for Signal Processing
    - Satellite communications, modems
    - Speech coding & digital signal processing
    - Telemetry systems & orbital tracking systems
- Mobile Communications Research Center
    - Cellular networks
    - Personal mobile terminals
    - Modulation & coding for R-LANs and cellular radio

(25-30 scientists in the two centers above)

- Center for Sensor Signal Processing

Naturally there is to be a very high degree of industry participation, and companies can locate R&D groups at SPRI, there is an industry affiliates program, etc. It is also hoped that SPRI will become the country's major center for postgraduate education in communications and signal processing. For information, contact

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DIRECTORY OF PARALLEL PROCESSING RESEARCH PROJECTS IN AUSTRALIA

In 1989, D. Abramson (CSIRO, Division of Information Technology) compiled a list of parallel processing research projects underway in Australia. This was published as a report, TR118 085R, from the Royal Melbourne Institute of Technology, 124 La Trobe Street, Melbourne, Victoria 3000, Australia, but can now be obtained from Abramson directly:

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SEISMOGENIC ELECTROMAGNETIC EMISSIONS AS PRECURSORS TO EARTHQUAKES AND VOLCANIC ERUPTIONS IN JAPAN

Since 1980, we have detected impulsive noise bursts of seismogenic emissions at 82 kHz, 1.525 kHz, and 36 Hz using our multipoint detection network around the Tokyo region and the Izu Peninsula. In earlier times, this system recorded electromagnetic signals prior to several earthquakes. It has recorded volcanic eruptions on 15 and 21 November 1986 at Mt. Mihara on Ohshima Island, on 12 July 1989 in Itoh Bay in the Izu Peninsula region, and from June to August 1991 at Mt. Unzen on the Shimabara Peninsula.

by Takeo Yoshino

INTRODUCTION

The Japanese-Soviet cooperative project for the study of electromagnetic emission phenomena related to earthquakes was started in 1980. The first emissions were observed at 16:33 JST (UT+9 hours) on 31 March 1980 at Sugadaira Space Radio Observatory, University of Electro-Communications, Sugadaira, Nagano Prefecture, Japan. The magnitude of this earthquake was about 7, and the depth of focus was approximately 380 km. The epicenter was located in Kyoto Prefecture, and the distance between the Sugadaira Observatory and the epicenter was approximately 250 km. The noise level recorder for 81 kHz registered an anomalously high change more than 15 dB over the usual background noise level, beginning 50 minutes before the main shock. The noise dropped sharply back to the previous level exactly at the moment of the earthquake. The very low frequency (VLF) whistler recorder at the Sugadaira Observatory also registered unusual impulsive emissions at frequencies below 1.5 kHz before the earthquake (Ref 1).

In the first decade, we observed several emission events in the 82-kHz range; since 1987 we have added two observation frequencies in the 1.525-kHz and 36-Hz ranges to our observation system. We have set up a multipoint direction finding network with eight observation points around the Tokyo area since 1985 (Ref 2 and 3). One of the most promising results was in the case of an "under foot" earthquake that occurred in southwestern Ibaragi Prefecture at 21:14 JST on 27 February 1982. The magnitude of this earthquake was 6.3 and the depth of focus was approximately 40 km. A retrospective prediction of the epicenter was provided by the direction finding network at the Suginami, Sugito, and Yatsugatake observation points. The earthquake subsequently occurred in the predicted area (Ref 4). Between 1985 and 1990 we recorded 26 samples of earthquakes by means of this network.

A major volcanic eruption occurred on Mt. Mihara in November 1986, and the 82-kHz direction finding network operating on Ohshima Island recorded several impulsive noise emissions prior to the eruptions. Since 1987, we have added two frequency bands (VLF at 1.525 kHz and extreme LF (ELF) at 36 Hz) to our multipoint network to improve the signal-to-noise (S/N) ratios because of the increase in 82-kHz background noise levels in the last decade (Ref 5). In July 1989, the area around Itoh City on the Izu Peninsula was struck by a series of locally very strong volcanic earthquakes. The city expands along the coast of Itoh Bay and is located about 35 km northeast of Izu-Ohshima Island. These volcanic earthquakes and volcanic vibrations ended with the eruption from a new volcanic center at the bottom of Itoh Bay on 12 July 1989. The author obtained several interesting correlations between LF, VLF, and ELF emissions related to these eruptions (Ref 6).

A volcano named Mt. Unzen on the Shimabara Peninsula, Nagasaki Prefecture, erupted in April 1991 after 200 years of rest. We have set up our 82-kHz, 1.525-kHz, and 36-Hz recording equipment on the northwest side of the crater. The distance between the location of our sensors and the crater is approximately 3 km. We have obtained several interesting results by following three different modes of activity of this volcano: (1) the pyro-slush flow, (2) the eruptions, and (3) the major pyro-slush flow with a chain of eruptions. These interesting data will be available in the near future.

RADIATION MECHANISM

Studies of the radiation mechanism of precursory electromagnetic emissions in Japan and the U.S.S.R. have been ongoing since 1981, but no clear or reasonable results have been obtained until now.

Gokhberg and his colleagues in the U.S.S.R. had tried two different approaches. In the first, they assumed that the source is located in the lower region of the ionosphere and that the source precipitates the plasma instabilities by a large gradient of the electric field and the geomagnetic field intensity at the epicenter region (Ref 7). But their explanation still remained as several unclear theoretical descriptions. In the second, they changed their explanation. They explained that these electromagnetic emissions were generated by microdislocations in the rocks prior to shallow earthquakes (Ref 8). The observation systems and the research approach of the Soviet groups shifted toward lower frequency regions, on the order of a few Hz, because these frequencies have been observed in the electric field variations in the lower and upper ionosphere by satellite observations since 1985 (Ref 9-11).

We have great trust in these estimations, but the results are not sufficient to explain the source mechanism of the emissions, the mechanism of the electromagnetic energy transmission in the soils and rocks from the earthquake focus to the earth's surface, and the mechanism of electromagnetic wave radiation at the surface of the ground. Laboratory experiments performed by our colleagues show that the rocks emit electromagnetic radiation when crushed (Ref 12). Similar emissions were observed by Cress et al. in the United States (Ref 13). The maximum emission levels in the frequency spectrum profile of Cress' data peak around 1.5 kHz. The spectrum profile of our natural VLF wideband emissions observed during the earthquake in 1980 (Ref 1) and the profile of laboratory observation results by Cress et al. show very good agreement with each other. These interesting results give us a very important explanation for the source mechanism of this emission. During the entire duration of the eruption of Mt. Mihara on 21 November 1986, the emissions were only observed when the dike of magma intruding into the mountain body caused the crushing of rocks.

To explain the mechanism of transmission of electromagnetic impulses from the source around the focus area to the surface of the ground, we have applied a surface mode transmission model. The conductivity along the fault plane is usually very high compared to values in undisturbed rock, and the conductivity gradient is distributed along the direction of the fault lines. Such characteristics of a fault surface promote surface mode propagation along the fault plane from the focus to the ground surface. We estimate that the optimum condition for wave propagation is 25 dB/10 km below the usual case for homogeneous soil and rocks at the same distance. To explain the radiation condition at the ground surface, we used the optimum impedance match between the surface and free space and calculated a voltage standing wave ratio (VSWR) of 1.5 using the optimum case when the fault terminates in a slot dipole antenna at the ground surface. Based on these results, the author will attempt to explain the source mechanisms for the electromagnetic precursor emission phenomena in this paper.

MODEL OF RADIATION MECHANISM OF SEISMOGENIC EMISSIONS

The author has offered a possible mechanism for the seismogenic electromagnetic radiation above. The emission will be induced as one of the kinds of boundary charge phenomena when the rocks around the focus of an earthquake are crushed under the very strong distortion forces increasing rapidly just prior to the earthquake. Laboratory experiments have been done by Mizutani (Ref 12) and Cress (Ref 13). In these experiments, very strong electromagnetic impulsive emissions were observed at the instant the specimen of rock was crushed under high pressure. The values of induced electromagnetic emission obtained were different for each kind of rock, wet or dry, and are dependent on the many different conditions at the time of observation. Comparing the observation results from Cress' experiments (Ref 13) and the example of natural emissions observed at Sugadaira (Ref 1), the natural and experimental data show very good agreement in frequency characteristics, with peaks around 1.5 kHz as above mentioned.

The author has built a model to explain the radiation mechanisms of seismogenic emission as follows. Usually the focus of an earthquake is located on the fault plane (Ref 14). When the distortion forces are increased in the fault area, the crushing of pieces of rock is initiated and the energy of induced electromagnetic impulses is emitted within this region in the fault.

The electrical conductivity inside and directed toward the fault line is usually higher than for the rock outside, this difference being approximately

20 dB or more. Also, a sheath structure of high dielectric soils (fault gouge) is often observed on the boundary surface of the faults. This condition will be able to support the surface mode of the TEM-electromagnetic propagation along the boundary of the fault, and the energy of the seismogenic emission will be able to be transmitted from the source depth to the earth's surface with very little attenuation as compared to the usual plane wave propagation outside the boundary. The surface mode propagation of electromagnetic waves was developed by Goubau (Ref 15) and Cullen (Ref 16), and today this advanced technique is often applied to microcircuit designs for compact equipment systems in the centimeter and millimeter wave bands. The profile of the surface boundary of a fault has a structure similar to a surface wave transmission line.

The results of the numerical simulation on the estimation of attenuation values for the surface mode wave propagation along the boundary surface of the fault are as follows:

(1) Resistivity outside of the fault is 10 kΩ/m.

(2) Resistivity inside of and parallel to the direction of the fault is less than 10 Ω/m.

(3) The specific dielectric constant at the boundary surface of the fault is 20 and outside the area of the fault it is 6.

(4) The frequency is 82 kHz, 1.525 kHz, and 36 Hz.

(5) The depth of focus is 50 km.

(6) Transverse magnetic (TM) mode.

The calculated value of total propagation loss when the depth of focus is 50 km for 82 kHz is approximately 63 dB, for the case of a dielectric sheath thickness of 10 m, and 65 dB for 20 m. In the case of 1.525 kHz, it is approximately 56 dB in power ratio. If a large quantity of acid water is contained in the fault, the propagation loss will decrease more than 10 dB from the above calculated values. If the ground surface is covered by homogeneous soil and rocks, the value of transmission loss for surface mode propagation is more than 25 dB below the value of plane wave propagation at the same depth.

The radiation impedance matching between surface mode feed and free space radiation mode by a slot antenna, which consists of the boundary between the top end of the fault and the ground surface, was also simulated for many types of matching systems. One of the best cases of VSWR values that can be obtained is 1.5 for this structure. We are continuing estimates and experiments on surface mode propagation and impedance matching for surface radiation by means of a scale model for higher frequencies.

OBSERVATION RESULTS FROM THE ERUPTION OF MT. MIHARA AND ITOH BAY

Volcanic microvibrations were observed at the Ohshima observatory from July 1986 onwards, but the anomalous impulsive noise emissions at 82 kHz did not appear until after 20 October 1986. Several clear burstlike emissions were recorded from 3-22 November. At 17:25 JST on 15 November, the first major eruption occurred in the main (old) crater. Anomalous burstlike emissions were observed from 10:00-16:00 JST on 14 November, 1 day before the major eruption, but were not observed at the time of eruption. The volcanic activity continued with violent eruptions, and the lava fountain reached heights over 200 meters. Lava flowed out from the summit crater to the caldera. The earthquake and volcanic microvibrations during the eruption in the summit crater continued violently, but burstlike emissions were not observed. The eruption activity of the main crater quickly decreased after the night of 19 November.

From 10:00-12:00 JST on 21 November, several strong burstlike emissions were observed. The strongest peaks during these emissions reached over 12 dB more than the background noise level. At the same time, strong local earthquakes started and continued until the evening. At 16:15 JST, the summit crater (old crater) erupted violently and at 17:45 JST new craters suddenly appeared in the virgin fields on the northwestern slope of the mountain. Lava flowed down rapidly towards the station at upper Motomachi, which has the largest population on this island. By special order from the mayor of Tokyo, a state of emergency was declared and all of the 10,000 inhabitants of the island, except for a few scientists, policemen, and firefighters, were evacuated until the early morning of 22 November. The major eruptions in new craters completely ceased on the morning of 22 November (Ref 17).

Since early April 1989, volcanic microvibrations and earthquakes have been observed at a very local area around Izu-Itoh City. After early June, the number and amplitude of these volcanic earthquakes increased significantly, and the number of earthquakes that could be felt increased to several hundred per day into early July. The number of observed magnetic field emissions at 1.525 kHz and 36 Hz at Ohshima Island increased from 1 July to noon of 11 July, but after noon of 11 July the characteristics and levels of emission seemed to change. A very large number of volcanic earthquakes occurred before noon of 11 July, but after this time, the volcanic activity changed suddenly from the volcanic earthquake mode to the strong volcanic variation mode. No clear emissions were observed during these violent volcanic vibrations during the afternoon of 11 July. At 16:24 JST on 13 July, the eruption started at a new crater in the bottom of Itoh Bay, which is located only 2.5 km from the city shore (Ref 6).

The key point in our observed data for these volcanic eruptions is that we received very many emissions during the time of active volcanic earthquakes, until approximately noon of 11 July. Then the mode of vibrations shifted from volcanic earthquakes to volcanic vibrations, and emission signals ceased. In the case of Mt. Mihara on Ohshima Island, the observed anomalous emissions from 10:00-12:00 JST on 21 November occurred 4 to 5 hours before the eruptions from the new craters on the virgin fields inside of the crater and on the mountain slope outside the caldera. A model to explain the eruption mechanism of 21 November was developed by Aramaki (Ref 18). We have applied his model to explain our observed results. The mechanism for these anomalous burstlike emissions is explained as follows:

(1) The magma flow to the eruption of the summit crater was supplied directly from the base magma as primary magma.

(2) The eruption in the new craters was created by new magma flows, forced up as dikes inserted into the mountain body on the morning of 21 November (Ref 18).

To explain the emissions at dike insertions, we apply the results of laboratory experiments by Mizutani (Ref 12) and Cress (Ref 13). We believe that the observed emissions on 21 November were produced by the rock crushing due to the insertion of dikes.

CONCLUSION

In our investigations of the noise source and propagation path of seismogenic electromagnetic emissions as a precursor of earthquakes, we used the experimental results of electromagnetic emissions due to the crushing of rocks (Ref 12, 13) to explain the mechanism of emission around the focus of the earthquakes. We also applied the theory of surface mode propagation of electromagnetic waves along the boundary surface of a fault to explain why the energy transmission of seismogenic emissions from the focus to the ground surface is less attenuated in comparison with the case of usual plane wave transmission. We roughly estimated the transmission loss by use of an optimum value and averaged measurements for a typical fault in the Kanto area. We then concluded that the total attenuation loss for a specific case of surface mode transmission and slot antenna radiation was 26 dB lower than the case of usual plane wave transmission without a fault. Also, we presented the results of observed electromagnetic emissions related to the volcanic eruption at Mt. Mihara on Ohshima Island during November 1986 and at Izu-Itoh City.

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Takeo Yoshino received a B.S.E.E. degree in 1953 from the University of Electro-Communications, Tokyo, Japan. In 1953 he joined the university's Department of Electronic Engineering as a research associate, becoming a professor in 1967. Since 1970 Prof. Yoshino has been the director of the university's Sugadaira Space Radio Observatory. From 1958 to 1960 and 1975 to 1977 he was at Syowa Station in Antarctica as a member of the Japanese Antarctic Research Expedition. At Antarctica his main field of interest was the analysis and investigation of the auroral phenomenon by natural radio wave emission observed by rockets and satellites. Today his research interests include the emission mechanism of electrostatic ion-cyclotron wave and VLF auroral hiss over auroral oval by satellite observation, the prediction of earthquakes and volcanic eruptions by seismogenic emission phenomena, the bioeffect of radio emissions in EMC, and observation and development of millimeter burst VLBI systems in radio astronomy. He received the IEEE-AP Best Paper Award in 1967. Prof. Yoshino is a member of IEICE and EPEMJ (Japan), IEEE and AGU (U.S.), URSI, IAGA, and COSPAR; is an advisory board member of the Zurich EMC Symposium, Wraclow EMC Symposium, and Lowell Observatory; and is the chairman of the IEEE-EMCS Tokyo chapter.

A NOTE ON CSIRO'S DIVISION OF OCEANOGRAPHY

This article describes the facilities, administrative structure, and various research programs of CSIRO's Division of Oceanography, located in Hobart, Tasmania.

by A. Zirino

BACKGROUND

The Commonwealth Scientific and Industrial Research Organization (CSIRO) is the research arm of the Australian Government. Its principal aims are to perform research beneficial to Australian industry and government; to lead and promote an expanded science and technology effort in Australia; and to collaborate with other research institutions, principally state and private universities and industrial laboratories, in bringing the results of research to practical fruition and community benefit.

CSIRO'S budget for 1988-1989 was A$466M ($358.5M). Of this amount, 75% was provided directly by Parliament, another 21% came from industry, and the rest came from revenues earned. Organization policy is formulated by a board composed of distinguished representatives from government, industry, and academia. The CSIRO chief executive is also a member of the board. Expenditures in 1988-1989 were largely for rural production and processing industries (40%), manufacturing industries (17%), mineral and energy industries (13%), and environment (14%).

CSIRO is composed of six institutes, each composed of about six divisions. The Oceanography Division is in the Institute of Natural Resources and Environment. The institute also contains Divisions for Atmospheric Research, Fisheries, Environmental Mechanics (hydrology and environmental quality), Water Resources, and Wildlife and Ecology.

Along with the Division of Fisheries, Oceanography is housed in a new (perhaps 8 years old) and rather splendid set of laboratories, library, and support facilities known as the CSIRO Marine Laboratories, located in Hobart, Tasmania. This is where I visited for 2 weeks in June 1991. The occasion was a meeting of SCOR (Scientific Committee for Oceanographic Research) Working Group 90: Chemical and Biological Oceanographic Sensor Technology. The chairman was Dr. Denis J. Mackey, head of the division's Environment Program.

RESEARCH OBJECTIVES

The primary objective of the Division of Oceanography is to "advance scientific knowledge of the physics and chemistry of the seas and oceans of the Australian region." This broad objective translates into "providing information on resource management, transport, defense, public use, and environmental control. It also provides a basis for determining the influence of the ocean upon local and global climate."

In pursuit of the primary objective, the Division of Oceanography carries out research in physical and chemical oceanography, two of the four classic oceanographic disciplines. (Presumably, biological oceanography is carried out in the Division of Fisheries, and geological oceanography is not, at present, a major priority.) The division uses satellites, ships, surface and subsurface moorings, and fixed stations combined with analysis, interpretation, and numerical modeling to carry out an integrated program. In this, the overall research program of the Division of Oceanography is very similar to the research program being carried out at major U.S. institutions such as the Scripps Institution of Oceanography or the Woods Hole Oceanographic Institution. Major differences include the absence of a significant number of graduate students (although students from local universities may carry out research at the CSIRO laboratories in conjunction with division investigators) and the fact that the research strategy comes via CSIRO policy, thereby limiting the "academic freedom" of individual investigators. Overall, however, the laboratory environment struck me as being quite comparable to that found in U.S. university-affiliated institutions. As in academic institutions, information is propagated via publications, reports, etc. As an outside referee for an internal promotion to senior scientist, a rank requiring international recognition, I can attest that promotion criteria are similar to those required to attain the rank of (full) professor at the major U.S. institutions.

The academic character of the laboratory is maintained by encouraging division scientists to maintain close collaborations with other institutions and investigators throughout the world. Furthermore, there is an active (reasonably funded) program to bring foreign scientists to Hobart and to send division scientists abroad. Clearly, this is not only desirable but a necessity, as Hobart is distant from many of the world's centers of marine science.

Recently, through the establishment of a new Cooperative Research Center (CRC), the division has been able to interact more strongly with the University of Tasmania. (The CRCs are a new initiative by the Australian Government to promote interaction between universities, industry, and government, particularly CSIRO.) Seventeen CRCs have just been announced and one of them is for study of the Antarctic and Southern Ocean environment. This CRC will be based at the University of Tasmania and is composed of participants from the Division of Oceanography and the Division of Atmospheric Research, the Australian Antarctic Division, the University of Tasmania, the Bureau of Meteorology, and the Bureau of Mineral Resources (Geology and Geophysics). This CRC will have an annual budget of A$3-5M ($2.31-3.85M), will have access to the new icebreaker *Aurora Australis*, and will have about 30 graduate and postdoctoral students. CSIRO staff members will be involved in the teaching of graduate courses and will be able to co-supervise thesis research. The participation in the CRC has guaranteed access to the *Aurora Australis* for division scientists participating in WOCE (World Ocean Circulation Experiment) and JGOFS (Joint Ocean Global Flux Study).

Another major asset of the division is the *R/V Franklin*, operated as a national facility available to all Australian marine scientists. The *Franklin* was launched in October 1984. It is a modern oceanographic ship 55 meters long, equipped with equally modern scientific equipment, including an interactive data-logging system, a Doppler current profiler, and onboard satellite imagery. In addition to its crew, the *Franklin* is staffed by an oceanographic data group responsible for the collection and processing of "routine" hydrographic and meteorological data.

ADMINISTRATIVE AND PROGRAM STRUCTURE

The Division of Oceanography consists of approximately 100 people, of which two-thirds are employed in research groups and the balance in support groups such as administration, library, shops, and *R/V Franklin* operations. The director of the division is Dr. A.D. McEwan. The research groups reflect the division's capabilities and administrative structure rather than current research projects. There are four groups in physical oceanography. The first, headed by Dr. J. Church, concerns itself with large scale ocean circulation and thermal structure and includes continental shelf oceanography. The second group, headed by Dr. C.B. Fandry, concerns itself with applications-oriented research, primarily the modeling of tidal and wind-driven circulation and internal waves. The third physical group, led by Dr. T.J. McDougall, includes remote sensing activities, electronic applications, and *R/V Franklin* activities. The last group, under Dr. Denis J. Mackey, includes activities in inorganic and organic chemistry and routine hydrology. In practice, personnel from the four groups work together in four interdisciplinary research programs, which are (1) Climate (Church), (2) Resources (Fandry), (3) Environment (Mackey), and (4) Technology (McDougall).

The Climate Program consists of three subprograms that reflect Australia's unique geographic interest in climate change:

(1) The ocean's role in the El Nino-Southern Oscillation (ENSO) phenomenon

(2) The ocean's role in climate change

(3) The Southern Ocean's role in climate change

More than for most countries, Australia's economy is particularly vulnerable to climatic changes. Thus, the program attempts to predict them with comprehensive numerical models of the atmosphere/ocean circulation. It also specializes in models of the southern hemisphere oceans, since regional patterns of climate variability and change are very important here. Project 1 examines local climate variability on periods of months to years through a comprehensive network of data-collecting devices, including measurements of air/sea heat exchanges, instrumented buoys, satellite measurements, and routine shipboard hydrography. Project 2 concerns itself with predicting climate change over decades and with studying the possible effects of greenhouse cases in the atmosphere. Project 3 deals with the role of the Southern Ocean in climate change. The division participates in major international programs such as the Tropical Ocean-Global Atmosphere (TOGA) project, WOCE, and JGOFS.

The Resources Program supports offshore activities in Australian waters, particularly those related to the commercial exploitation of those waters. Subprograms include:

- Prediction of tides and currents for offshore resources

- Surface wave climatology and prediction

- Characterization and prediction of major ocean current system and continental shelf oceanic processes in Australian waters

- Biological and chemical resources

The first three involve the development of suitable predictive numerical models as well as intensive sampling. Coastally trapped waves in regional currents are being investigated. The fourth subprogram includes engineering applications, including assessment of local wave power resources, assistance in mariculture projects, and possible commercial exploitation of the oils of local fish.

The third research program, Environment, combines analytical chemical technology (both organic and inorganic) with field sampling technology and modeling to produce a program in marine environmental quality assessment. It has been recognized that water quality criteria for Australian waters, as for waters anywhere, are based on inadequate data and a very meager understanding of how trace levels of toxins in water interact with organisms. Furthermore, there is virtually no understanding of the chemical forms (speciation) that trace substances assume in water, even though it is well understood that toxicity depends on chemical form. Thus, more data are needed to be able to establish better environmental guidelines. Current research is aimed at obtaining a better understanding of the processes that affect the concentrations of trace substances in seawater. Subprograms are underway to study heavy metals and organic pollutants. The laboratory is equipped with cleanroom facilities and up-to-date instrumentation, including a Zeeman atomic absorption spectrometer, polarographic equipment, four capillary gas chromatographs with mass spectrometry, and equipment for thin-layer chromatography.

A parallel program is underway to study CO_2 in surface waters. An underway system for measuring pH and pCO_2 has been developed and installed aboard the *R/V Franklin*. Because the CO_2 data are a critical component of global CO_2 temperature models, careful calibrations of the equipment are underway in conjunction with other laboratories around the world.

The fourth and final program, Technology, develops special technologies in support of the other research programs. It also participates in the commercialization of any products that might result from the research. A principal development of the Technology Program is the Bunyip system for measuring oceanic microstructure. Bunyip is deployed from the *R/V Franklin* and consists of two towed bodies. The first, at the end of 5,000 meters of cable, is able to undulate or "porpoise," while the second, trailing 100 meters behind, measures the temperature microstructure with especially devised sensors. The two towed bodies communicate at 375,000 bps on a local area network, and the sensor data are displayed aboard the *Franklin*. The system is being updated constantly.

CONCLUDING REMARKS

In summary, CSIRO's Division of Oceanography appears to combine what is best about university and government laboratories: a highly qualified and motivated staff and steady funding, albeit with strings attached. In this manner it resembles U.S. national laboratories such as Brookhaven or Los Alamos. A unique aspect of the Australian laboratory is that it encourages interaction with private industry; indeed, it seeks nongovernment funds. Unlike the United States, where the presence of private industry in government laboratories is viewed with suspicion, Australians seem to have no difficulty with possible commercialization of the products of joint research. I suppose this is because in Australia, a country of 17 million, the link between the prosperity of private industry and the general welfare is clearly understood by all. Similarly, the mandated oceanographic research policy tightly reflects national needs. This creates a consensus of opinion and a sense of mission shared by all the scientists and staff of CSIRO's Division of Oceanography that I contacted.

A. Zirino has been a U.S. Navy scientist for 22 years. During that time he has worked on developing electrochemical techniques for measuring seawater constituents in real time and on developing strategies for mapping oceanic chemistry. He is Adjunct Professor of Chemistry at San Diego State University and Professor of Oceanography at the Universidad Autonoma de Baja California, where he teaches at the Ensenada, Mexico, campus.

PANEL MEETING OF THE INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION'S GEOLOGICAL-GEOPHYSICAL ATLAS OF THE PACIFIC AND ATLANTIC

Publication of the folio Atlas of the Atlantic Ocean *is announced. Progress on the companion* Atlas of the Pacific Ocean *is reviewed, with major contributions from Japanese ocean scientists and agencies. Advances in survey instrumentation and computer data handling and display indicate higher resolution and more detailed coverage in the Western Pacific.*

by Pat Wilde

Under the chairmanship of Acad. G. Udintsev, editor in chief, the editorial board of the *International Geological-Geophysical Atlas of the Pacific* met from 9-11 September 1991 at the Ocean Research Institute of the University of Tokyo in Tokyo, Japan. This atlas, sponsored by the Intergovernmental Oceanographic Commission (IOC) of UNESCO, is the third in a series, with initially the Indian Ocean (1975) and most recently the Atlantic Ocean (1991) atlases being published. The atlas series is being compiled and produced in Moscow with text, captions, and legends in both Russian and English. The Pacific atlas is projected to be about 200 folio size pages. As of June 1991, 114 geologic, geophysical, or geochemical topics are to be depicted as maps, profiles, and suitable diagrams. Maps showing total oceanic features will be at 1:30 million or 1:10 million. Regional maps of areas such as marginal seas will be at 1:5 million. Special study areas like the Juan de Fuca Ridge will be at appropriate larger scales. In addition to the conventional maps, etc., there will be sections on the history of the cartography of the oceans, research ships contributing data, and discussions on the development of new research techniques including progress in navigation, acoustic sea floor mapping systems, reflection seismic surveying, deep seismic studies by refraction methods, Magsat maps, measurement of gravity at sea, methods in geothermal studies of the ocean floor, deep sea drilling, submersibles, tomography, and bottom topography-source materials. Three appendices showing world ocean bathymetry, magnetic lineations of the world's ocean basins, and world seismicity 1979-1988 will complete the atlas. A publication date of late 1993 to early 1994 is planned. As expected for a project of this magnitude (the Pacific Ocean covers half the surface area of the Earth!), the contributors are from a broad spectra of the international oceanographic community.

Board members in attendance in Japan, besides editor Udintsev, were deputy editor D.P.D. Scott, (IOC) Paris; B. Lewis, University of Washington; E. Litvinov, Institute of Ocean Geology, St. Petersburg, U.S.S.R. (representing Acad. Gramberg); M. Talwani, Rice University; S. Uyeda, Tokai University, Tokyo, Japan; and D. Zhiv, Administration of Geodesy and Cartography, Moscow, U.S.S.R. This meeting of the Central Editorial Board was to announce the completion of the Atlantic atlas and to review the status of the Pacific atlas. Holding the meeting in Japan was particularly useful as the Japanese ocean scientists and agencies are major contributors, not only of data near Japan but they also are doing a major portion of the compilations at both regional and oceanic scales involving data collected by many countries.

Japanese participants making individual presentations discussing specific plates and maps were: A. Asamuna, Chiba University, *sediment thickness*;

E. Honza, Geological Survey of Japan, *Melanesia*; N. Isezaka, Chiba University, *magnetics*; M. Ishida, National Research Institute for Earth Sciences and Disaster Prevention, *seismicity*; H. Kinoshita, Earthquake Research Institute, *Okinawa Trough*; K. Nemoto, Tokai University, *sediment thickness*; N. Sugi, Kyoritsu Women's University, *seismicity*; K. Suyehiro, Ocean Research Institute, *Nankai Trough*, *Japan Trench*, *crustal structure*; S. Tani, Maritime Safety Agency, *SeaBeam 2000 surveys*, *general bathymetry of Western Pacific*; and Y. Tsuji, Earthquake Research Institute, *tsunamis*.

Of particular interest were the presentations on sediment thickness, SeaBeam surveys, and seismicity. Dr. Nemoto of the Faculty of Oceanography, Tokai University, described a PC-based system whereby sediment thickness data from various sources and quality could be assessed, merged, and plotted via a ranking system program. This method seems a logical approach to a thorny problem of integrating survey data taken at various times, by different ships, using a wide array of equipment, and displaying it on a single computer-generated base. Dr. Tani of the Japanese Hydrographic Department showed advanced copies of the bathymetric charts being prepared by the Maritime Safety Agency for the Japanese Exclusive Economic Zone. The charts with the accompanying magnetics and gravity were of such high quality and resolution that they were essentially textbook visual examples of different types of marine geologic and plate tectonic features. Dr. Ishida, National Research Center for Disaster Prevention, and Dr. Sugi, Kyoritsu Women's University, displayed color three-dimensional (3-D) plots of seismic epicenters for Japan and the Peru-Chile Trench areas and a novel plot of seismic activity in the Western Pacific Ocean and Indian Ocean on a globe. With the use of red-green glasses, these 3-D pictures were vivid portrayals of the subducting plates, plate boundaries, and the structure of Benihoff zones.

The panel tentatively plans to meet next year at either the International Geologic Congress in Kyoto, Japan, or in Hawaii to discuss further progress in the preparation of the Pacific atlas.

The author wishes to thank Dr. Uyeda, Dr. Udintsev, and Dr. Scott for their kindness in inviting me to attend the panel meetings as an observer. Also, great credit is due to the director, Dr. Tomio, and his staff at the Ocean Research Insti[illegible] University of Tokyo, for their ma[illegible]rtesies as gracious hosts of th[illegible]g.

Pat Wilde joined the staff of the Office of Naval Research Asian Office (ONRASIA) in July 1991 as a liaison scientist specializing in ocean sciences. He received his Ph.D. in geology from Harvard University in 1965. Since 1964, he has been affiliated with the University of California, Berkeley in a variety of positions and departments, including Chairman of Ocean Engineering from 1968 to 1975 and Head of the Marine Sciences Group at the Lawrence Berkeley Laboratory (1977-1982) and on the Berkeley campus (1982-1989). He joined ONRASIA after being the Humboldt Prize Winner in Residence at the Technical University of Berlin. Dr. Wilde's speciality is in paleo-oceanography and marine geochemistry, particularly in the Paleozoic and Anoxic environments. He maintains an interest in modern oceanography through his work on deep-sea fans, coastal and deep-sea sediment transport, and publication of oceanographic data sheets showing the bathymetry with attendant features off the West Coast of the United States, Hawaii, and Puerto Rico.

THE PHYSICS OF PSEUDOBINARY SEMICONDUCTORS

In recent research results from Japan, both random-alloy and atomically ordered pseudobinary semiconductive epitaxial heterostructures show remarkable transport properties. Some of the physical implications are discussed in this article.

by Victor Rehn

INTRODUCTION

After years of study of pseudobinary ternary semiconductor (PTS) materials such as $Al_xGa_{1-x}As$, $In_xGa_{1-x}As$, $GaAs_{1-y}P_y$, or $GaAs_{1-y}Sb_y$, or related pseudobinary quaternary semiconductor (PQS) materials, application of such materials in a variety of semiconductor devices is now commonplace. $GaAs_{1-y}P_y$ and $In_xGa_{1-x}As_{1-y}P_y$ materials are widely used in light-emitting diodes (LEDs) and lasers, $In_xGa_{1-x}As$ and $Al_xGa_{1-x}As$ materials are used in field effect transistors (FETs) and infrared detectors, and $In_xGa_{1-x}As$ materials are used in the lasers and detectors that are the heart of the 1.3- to 1.6-micron fiber-optic communication systems. In these applications, the use of PTS or PQS materials has introduced higher electron mobilities, lower effective masses, or precisely tailored bandgaps, all available uniquely in PTS and PQS materials. In spite of the well-developed technology, research in PTS and PQS material systems continues to excite researchers. In this article, some of the physical background and the research interest in these complex material systems are explored, and progress recently reported in Japan is outlined.

The majority of PTS and PQS systems studied have been III-V material systems, although increasingly II-VI PTS or PQS materials and other ternary material systems are attracting research interest currently. As the technological success of the better understood PTS materials becomes evident, researchers are encouraged to attempt even greater control of important electronic, optical, and electrooptical properties in more and more material systems. Some of the basic physical questions that were matters of concern years ago still remain to be answered, but recent research is providing surprising answers to old questions and a host of new research opportunities.

BACKGROUND

PTS and PQS materials can be grown in most III-V and many II-VI systems in single crystal form over the entire range of the compositional parameters, x or y. Early research was conducted with bulk crystals grown by vapor growth methods. X-ray diffraction analysis showed that these crystals are of the same crystal structure (zinc-blende) as crystals of the "parent" binary compounds, and that the lattice constants vary linearly between those of the parent compounds, obeying Vegard's law. The zinc-blende structure can be represented accurately as two interpenetrating face-centered cubic (fcc) lattices, offset diagonally from each other by one-fourth of the unit cell. In a perfect pseudobinary crystal, each fcc sublattice is occupied exclusively by metal or by ligand atoms.

X-ray analysis also showed that the two (metal or ligand) atoms sharing a single sublattice are randomly distributed among the sublattice sites, with the probability of occupation determined by the compositional parameter. In $Al_xGa_{1-x}As$, for example, one fcc sublattice is occupied entirely by As atoms, while the other fcc sublattice holds a random distribution of Al and Ga atoms. Hence, these materials have been referred to as random-alloy semiconductors.

It was soon found by electroreflectance, optical absorption, and other measurements that the bandgap, also, varies with the x value, but quadratically instead of linearly. Hence, "bandgap engineering," compositionally controlling the bandgap to suit the application, has been practiced successfully in many PTS and PQS material systems. Bandgap engineering in the InGaAs system was the enabling technology for exploitation of the minimum in optical absorption and dispersion in quartz fibers at 1.3 and 1.55 microns.

The most basic theorem of solid-state physics is the Bloch theorem, which has been the basis for understanding the quantum eigenstates of electrons in solids since 1933. Because the Bloch theorem relies on the infinite periodicity of the crystal lattice, theoretical understanding of electronic states in solids with random atomic positions was not possible with the Bloch theorem alone. The earliest success calculating transport and optical properties of PTS and PQS materials utilized the concept of a virtual crystal, in which the Bloch theorem can be used. In a virtual crystal, occupied valence bands and empty conduction bands can be envisioned, accompanying free Bloch electrons with crystal momentum values as good quantum numbers.

Taking $In_xGa_{1-x}As$ as an example ($0<x<1$), the virtual $In_xGa_{1-x}As$ crystal is one in which the metal-atom fcc sublattice is occupied by fictitious atoms composed of the proportion x of an In atom and 1-x of a Ga atom. This fictitious atom is easily created in the computer as the weighted sum of atomic potential functions of In and Ga. This conceptual model of a random-alloy PTS can be handled theoretically as a binary-compound crystal in the calculation of the band structure, bandgaps, effective masses, optical absorption edges, dopant states, and the like. Additional theoretical developments added effects of the randomness of the atomic sites by adding an additional mechanism for the scattering of charge carriers and broadening of the band edges. The alloy scattering term was verified experimentally and shown to limit the rise in carrier mobility at low cryogenic temperatures. It is important to note that alloy scattering becomes a dominant scattering mechanism only at very low temperatures, so that the interesting semiconductor properties of PTS materials are not jeopardized for room temperature applications. Remarkably, the transport and optical properties of the virtual crystal closely mimic those measured for real PTS and PQS crystals.

Although skeptics had long wondered, the first conclusive evidence that the structure predicted by the virtual crystal is inaccurate on the atomic scale was obtained by Michelson and Boyce of Xerox Palo Alto Research Center in 1981, using measurements of interatomic distances by extended x-ray absorption fine structure (EXAFS). In contrast to x-ray diffraction, experimenters using EXAFS (a synchrotron-radiation based technique) are able to measure interatomic distances between individual atomic species: the In--As bond length is obtained separately from the Ga--As bond length in an EXAFS analysis of $In_xGa_{1-x}As$, for example.

In the binary-compound crystals, the In--As bond length is 0.2614 nm and the Ga--As bond length is 0.2448 nm, while in random-alloy pseudobinary $In_{0.5}Ga_{0.5}As$ the average metal-ligand bond length obtained from x-ray diffraction is 0.2531 nm, in agreement with Vegard's law. In the zinc-blende crystal structure, all interatomic distances are necessarily the same. X-ray diffraction results detected no departure of the crystal structure from zinc blende and showed that the variation of the lattice constant with composition obeys Vegard's law in several PTS and PQS material systems. The EXAFS results, however, showed clearly that, as the compositional parameter is varied, the length of the In--As and Ga--As bonds, while not constant, varies much less than required by Vegard's law, and that the average bond length obeys Vegard's law.

Confirmation of the EXAFS results in several PTS systems increased the motivation to look closely at the question of whether the occupation of sites on the fcc sublattice by one or the other metal atom is always random or might, in some cases, be ordered. If bond lengths are partially controlled by chemical considerations, then the total energy of the crystal should be reduced in an ordered arrangement, as compared with a random distribution. This time many skeptics aligned themselves on the wrong side of the question, but results obtained over the past few years have proved conclusively that ordered PTS materials can and have been grown epitaxially (Ref 1). More complex crystal structures related to the cubic zinc-blende structure are obtained, and some fascinating properties are expected (Ref 2). At the present time, experimentalists and theorists are busily exploring the structural types, stability, and possible electrical, optical, and electrooptical properties of ordered PTS and PQS epitaxial crystals and various quantum heterostructures utilizing them.

TYPES OF ORDERING IN PTS AND PQS MATERIALS

To understand the possible effects of ordering on properties such as the band structure, it may be useful to distinguish two types of ordering and the ways in which the electronic energy-band structure may be changed in each type. The fundamental periodicity of the crystal lattice, which is the same in all three coordinate directions in cubic crystals such as zinc blende, determines the symmetry nature of the momentum space (reciprocal space) in which the electron momentum quantum numbers are represented.

In Type 1 ordering, a sublattice grossly alters the fundamental periodicity of the crystal, resulting in gross changes in the electron energy bands. Type 1 ordering occurs when epitaxial growth of the ordered PTS or PQS causes the fundamental period of one or both sublattices to double, triple, or quadruple along the growth direction, for example. Then the reciprocal-lattice period along the growth direction is halved, thirded, or quartered, respectively, and the electron-energy bands are folded back from the reduced Brillouin-zone boundary at lower values of electron momentum. The result is a greater number of valence and conduction bands, each with fewer electron states, and usually dispersed over a smaller range of energies. New "mini" bandgaps may be created, and the fundamental optical absorption spectra may be drastically altered by rearrangement of energy-band maxima and minima and the associated critical points in the interband density-of-states function.

Type 2 ordering occurs when the ordering or placement of atoms is representable within a single unit cell of the parent zinc-blende crystal. In growing $In_{0.5}Ga_{0.5}As$ on a (100) plane of a zinc-blende substrate, for example, the metal-sublattice planes can be alternately planes of In or Ga atoms, instead of each plane being randomly occupied by equal numbers of In and Ga atoms. Of course, any changes in the atomic positions within the unit cell are expected to change the lattice constant, but only small changes are expected to result from Type 2 ordering. While not grossly changing momentum space, Type 2 ordering will generally induce lattice distortions that reduce the crystalline symmetry from cubic to tetragonal, trigonal, or orthorhombic, depending on which crystalline plane epitaxial growth occurs. Type 2 ordering affects the band structure in more subtle ways, such as inducing asymmetry splitting of degenerate valence bands, or changing the effective masses and their isotropy, or changing the location and type of interband critical points. Significant changes in the optical, electrooptical, and transport properties should be observed in many cases of Type 2 ordering. Ordering of either type should eliminate the alloy scattering of charge carriers referred to above and therefore eliminate the limitation on the low-temperature electron mobility achievable.

In quantum-confined structures, details of the band structure become even more important. Small changes in relationship of band structures or quantum states in neighboring thin epitaxial layers may induce gross changes in transport or other properties. In the design and development of quantum-well lasers, for example, the possible use of ordered PTS or PQS epilayers may improve device performance significantly. In optoelectronic integrated circuits (ICs) fabricated in III-V, II-VI, or other materials, ordered PTS or PQS materials may enhance electrooptical effects and provide new technological possibilities. Hence, it was not surprising to find evidence of an increasing level of research activity in ordered PTS and PQS epilayers, both in III-V and II-VI systems.

Two of the strong research programs for ordered PTS and PQS materials in Japan are those at the Fujitsu Laboratories, Ltd. and at Kyushu University. The latter program includes an effort to model the growth process, as previously reported (Ref 3). Recent results on ordered growth of the CuPt type (a Type 2 structure) on (001) substrates show that stable ordered PTS crystals can be produced even though the corresponding bulk crystals have no stable ordered ternary phases (Ref 4). The interfacial bonding stabilizes the otherwise unstable ordered epitaxial layer. Total energy considerations will limit the maximum thickness for stability, of course, as can be estimated for specific structures and compositions. Hence, we can anticipate a new type of critical thickness associated with the maximum thickness for stable ordering. No discussions of this question have appeared in the literature to date.

At Fujitsu Laboratories, Ltd., Drs. O. Ueda, Y. Nakata, T. Nakamura and T. Fujii have conducted transmission electron microscopy (TEM) investigations of ordering in molecular beam epitaxy (MBE) grown InGaAs crystals grown on (110) InP substrates (Ref 5). Superstructure spots indicative of the CuAu-I-type crystal structure are found in x-ray diffraction data, and high resolution TEM data show a doubling of the period in 220 and 200 lattice fringes. The CuAu-I-type structure is an orthorhombic (pseudo-tetragonal) structure, also Type 2, in which planes of InAs and GaAs alternate during growth.* Because the resulting $InGaAs_2$ composition is near the lattice-matching composition ($In_{0.53}Ga_{0.47}As$) for growth on InP substrates, strain effects are minimal.

In studying the influence of substrate-surface orientation on ordering, it was observed that increased strength of the superstructure spots is obtained from crystals grown on vicinally tilted substrate surfaces. Tilting by 1° to 5° toward either the <001> or <00$\bar{1}$> directions in the (110) plane produced greater ordering than tilting toward the <1$\bar{1}$0> direction. This anisotropy in growth quality in itself indicates that the step-growth mechanism plays an important role in the ordering of the PTS epilayer.

Growth of these ordered crystals was accomplished by normal MBE techniques at substrate temperatures in the 360- to 450-°C range. At such low growth temperatures, the interfaces are shown to be very sharp, but the imperfection density is high. Antiphase grain boundaries are frequently found between platelet-like microdomains lying on slightly tilted planes.

* It should be noted that the same average composition can be grown in either Type 1 or Type 2 structures in many cases. If the growth sequence is two InAs layers followed by 2 GaAs layers, then a Type 1 structure will result with the same average composition, $InGaAs_2$ or $In_2Ga_2As_4$. These Type 1 structures are referred to in the literature as short-period superlattices.

TRANSPORT PROPERTIES

In spite of the less-than-perfect crystals, the transport properties reported are outstanding (Ref 6). Two two-dimensional electron gas (2DEG) samples were made with ordered InGaAs/n-type InAlAs/InP, a system with minimal strain because of the near matching of the PTS crystal lattice constants with the InP substrates. The 2DEG electron concentration was about 1×10^{12} cm^{-2} in each sample, but the substrate orientation was (110) in sample #1 and (001) in sample #2. In both samples, the mobility rose steeply as temperature was decreased, reaching more than 150,000 cm^2/V-s in sample #1 and more than 100,000 cm^2/V-s in sample #2. It is important to note that in both samples, the mobility at cryogenic temperatures exceeded the theoretical limitation imposed on random-alloy materials by alloy scattering. The mobilities are claimed to be the highest ever reported for a lattice-matched PTS crystal.

It is yet to be determined what the effect of pseudomorphic strain may be on ordered PTS crystals. In random-alloy PTS crystals, very high mobilities have been reported. A recent example is from the Electrotechnical Laboratory in Tsukuba, Japan (Ref 7). In this study, the mobility of an $In_xGa_{1-x}As$ 2DEG layer was shown to increase by nearly 40% as x increased from the lattice-matched value of 0.53 to the optimal value of 0.8. The InGaAs 2DEG layers were isolated between lattice-matched $In_{0.52}Al_{0.48}As$ barrier layers, with the addition of one-half or one monolayer of InAs at the interface, in a structure grown at 450 °C. In addition, great care was taken to reduce the metal-flux overshoots normally associated with shutter opening. This reduction was accomplished by using a furnace-temperature control function with a square-root ramp. At cryogenic temperatures, the mobility measured for optimally pseudomorphically strained (x=0.8) 2DEG epilayers rose to 112,000 and 157,000 cm^2/V-s, respectively, at 77 and 10 K. While these mobility values remain far below the highest mobilities reported for GaAs at temperatures less than 1 K, it is now apparent that there is no fundamental reason for not achieving similar high mobilities in ordered PTS epilayers.

CONCLUDING REMARKS

Many research and technological opportunities are apparent in the future of ordered PTS and PQS materials. Controlling effective masses via compositional control, eliminating alloy scattering via ordering, reducing phonon scattering via 2DEG confinement, and further tailoring the band structure with pseudomorphic strain may produce amazing electronic, optical, electrooptical, and optoelectronic material properties in the future.

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RESEARCH ON III/V SEMICONDUCTORS

This article summarizes the important advances in the area of III/V semiconductors reported at the 7th International Conference on Vapor Growth and Epitaxy and the 10th Symposium on Alloy Semiconductor Physics and Electro.ics and the impressions gained from visits to seven research laboratories.

by G.B. Stringfellow

INTRODUCTION

I will summarize the important advances reported at both the 7th International Conference on Vapor Growth and Epitaxy (ICVGE) and the 10th Symposium on Alloy Semiconductor Physics and Electronics (ASPE), a satellite conference), in the area of III/V semiconductors. Since up to four sessions were conducted in parallel for ICVGE, this report cannot include summaries of all important results reported. Only the key talks, describing significant advances, will be mentioned, by subject area. In addition, impressions gained from visits to seven research laboratories will be briefly summarized.

ORGANOMETALLIC VAPOR PHASE EPITAXY (OMVPE)

"Hydride Group III Precursors for the MOVPE of AlGaAs/GaAs Heterostructures" (H. Protzmann, T. Marschner, O. Zsebok, W. Stolz, E.O. Bobel, R. Dorn, and J. Lorberth, Philipps-Universitat, Marburg, Germany). An important area of research on new precursors involves the search for new Al and Ga molecules that give less carbon contamination than the normally used trimethyl compounds of gallium and aluminum. Within the last 18 months researchers in both England and the United States have reported successful growth of AlGaAs using trimethylaminealIane (TMAA), an adduct compound of allane (AlH_3) and trimethylamine [$(CH_3)_3N$]. The latter stabilizes the group III hydride, which is otherwise too unstable to use for vapor phase growth. The equivalent gallane-adduct molecule is not sufficiently stable for OMVPE, although it may be useful for chemical beam epitaxy (CBE) where no gas phase or wall collisions occur. The most successful molecule reported in this talk (not included in the abstract) is dimethylaminegallane [$H_3GaNH(CH_3)_2$ or DMAG]. The authors reported the synthesis route and found that it was stable when stored and used below room temperature. (During questioning they also admitted to Ga deposits in the lines.) This will limit commercial usefulness of this precursor, but they claim to be on the trail of other, more stable alternatives. The vapor pressure was reported to be 2 mbar at 10 °C. They successfully used the new precursor for GaAs growth at reduced pressure (50 Torr) in a commercial Aixtron reactor with either arsine or tertiarybutylarsine (TBAs) as the As source. In the temperature range from 600 to 650 °C, the TBAs was more efficient; lower V/III ratios could be used for the growth of high purity material. They obtained reasonable impurity levels in the low 10^{16} cm^{-3} range with 77K electron mobilities of 10,000 cm^2/Vs. They used DMAG along with TMAA and arsine to grow AlGaAs and GaAs/AlGaAs quantum wells with widths of 15, 45, and 100 Å, giving excellent photoluminescence characteristics.

"Reduction of Carbon Contamination in TEP-OMVPE GaP Layers by Pt/Al_2O_3 Catalyst" (X.L. Wang, A. Wakahara, H. Kuwahara, S. Noda, and A. Sasaki, Kyoto University). Another novel approach was the use of the phosphorus precursor triethylphosphine (TEP) for the growth of GaP. This precursor has been thought to be too stable for use as a P source; however, Sasaki's group showed that it can be used with trimethylgallium (TMGa) for GaP growth, but only at high temperatures (>700 °C). The triply substituted group III alkyls are well known to give excessive levels of carbon contamination. Thus, the authors used a Pt/Al_2O_3 catalyst to decompose the H_2 ambient, giving atomic H, which is known to reduce carbon contamination in the epitaxial solid. They found, from secondary ion mass spectometry (SIMS) measurements, that the catalyst did, indeed, reduce the carbon concentration in the GaP from the low 10^{17} cm^{-3} range by approximately an order of magnitude. It should be mentioned that another phosphorus precursor, tertiarybutylphosphine (TBP), is available that gives much higher quality epitaxial layers. The advantage of

TEP may be that it is cheaper. However, the quality of the layers is much inferior, so it is not clear whether this line of research will be fruitful, although the addition of H to the system to reduce carbon is an interesting and potentially useful idea for other systems.

"MOVPE Grown HEMT LSIs" (J. Komeno, Fujitsu Laboratories). A very significant practical paper was a late news contribution from Fujitsu. They use a large-scale reactor capable of handling 12 3-inch GaAs substrate wafers per run. They have previously reported the excellent material quality and uniformity obtained as well as the superior quality high electron mobility transistors (HEMTs) produced. In this large barrel reactor, both the susceptor and the individual wafers are rotated during growth. Now the technique is moving toward production for circuit manufacturing. Because of the lower defect density, OMVPE has apparently proven superior to molecular beam epitaxy (MBE) (the technique originally used by Fujitsu for the manufacture of individual HEMT devices). The large-scale OMVPE technique has now been used to produce large-scale integrated (LSI) circuits, specifically 64K SRAMS. The process is slightly different than that normally used. TMGa (combined with arsine) is used to grow most of the layers, but for the layers where thickness is extremely critical, triethylgallium (TEGa) is used. The lower vapor pressure gives lower growth rates and more precise control of the layer thickness. Trimethylaluminum (TMAl) is used for the AlGaAs layers. The n-type dopant is disilane. The reactor was operated at reduced pressure (80 mbar) at a temperature of 680 °C. As mentioned above, the number of surface defects or particles is lower for OMVPE-grown layers. They measured defect densities of 8 cm^{-2}, much lower than for similar structures grown by MBE. Layer thickness and doping levels were uniform to within 1% and 2%, respectively. More importantly, for production, the pinch-off voltage was found to vary by only 140 mV over a period of 8 months with 25 runs/month on average. The standard deviation on a circuit was approximately 12 mV. For the 64K SRAM, the HEMT gate length was 0.6 μm. This yields devices with a transconductance of 340 mS/mm and a cut-off frequency of 38 GHz. The chip size is 7.4 by 6.6 mm. A typical access time was 1.2 ns with a power dissipation of 5.9 W.

MOLECULAR BEAM EPITAXY (MBE) AND MIGRATION ENHANCED EPITAXY (MEE)

"Recent Progress in MBE and MEE" (Y. Horikoshi, Y. Hirayama, and T. Saku, NTT Basic Research Laboratories). Horikoshi gave an invited talk discussing the latest developments in MBE and MEE, a technique developed by NTT. By using extremely long bake times (20 days at 200 °C), NTT has succeeded in reproducing the earlier reported AT&T results of extremely high ($>10^7$ cm^2/Vs) low temperature mobilities in modulation doped GaAs/AlGaAs structures. Attempts to obtain such extremely high mobilities by MEE have failed because it is more difficult to retain high purity levels since the Ga-stabilized surface is repeatedly exposed to the ambient. (During MEE, the flux of precursors is stopped every monolayer to allow the atomic steps to move on the surface.) Even under the best conditions, contamination and some degree of oxidization occur. Nevertheless, they have obtained 4.2K mobilities of 3.5 x 10^6 cm^2/Vs. Routine growth by MEE also causes significant problems with conventional shutters, since they must be opened and closed 4,000 times/μm of growth. (When I visited NTT I learned that they have developed a new type of sliding shutter to solve this problem.) MEE occurs effectively in MBE-like conditions only when the direction of (100) substrate misorientation is such that [110] steps are produced. The asymmetry between the motion of [110] and [-110] steps on the surface also gives rise to asymmetric islands for growth in the two-dimensional nucleation mode in MBE. They reported that this gives rise to anisotropic transport in the two-dimensional electron gas, with the resistivity in the [-110] direction being systematically lower than the resistivity in the [110] direction. This asymmetry is not seen in structures grown using MEE. A very interesting outcome of the very high low-temperature mobilities is the ability to directly observe ballistic motion of electrons. For a van der Pauw sample 30 μm on a side, electrons can move from one electrode to the other without scattering, since the mean free path between collisions is approximately 70 μm. This gives rise to nonlinear I-V characteristics, since Ohm's law is not obeyed by ballistic electrons.

SURFACE PROCESSES DURING MBE, MEE, AND OMVPE

This is a rapidly advancing area of research. The homogeneous pyrolysis processes have been extensively studied in the authors' group as well as in several others. However, little information is available about the actual processes occurring at surfaces. This involves both the surface catalyzed, heterogeneous chemical reactions occurring as well as the physical processes of reconstruction, step and kink motion, surface diffusion, etc. These are extremely important processes that we are only now beginning to be able to study. It is also an area where a great deal of work is being initiated in Japan, as well as in other parts of the world. Since this conference drew most speakers from Japan, this was an excellent opportunity to catch a glimpse of the most advanced work in Japan.

"Step-Flow Growth and Fractional-Layer Superlattices on GaAs Vicinal Surfaces by MOCVD" (T. Fukui and H. Saito, NTT Basic Research Laboratories). Fukui gave an invited presentation at ICVGE dealing with the growth of vertical or fractional-layer superlattices by OMVPE. The horizontal reactor operated at 76 Torr using TEGa, TEAl, and arsine to give controllably low growth rates (0.47 Å/s) at 600 °C. The nominally (001) GaAs substrates were misoriented by 1°-2° in either the [-110] or [110] direction to introduce steps with the proper spacing and orientation on the surface. As predicted some years ago by Petroff, the proper combination of substrate misorientation and growth cycle gives rise to the growth of a structure on each step so that half is GaAs and the other half is AlGaAs. As this is repeated for layer after layer, a vertical superlattice is produced. For misorientation to give [-110] steps, uniform superlattice structures with essentially flat layers were produced. I believe this is the first time such a perfect superlattice has been grown by any technique. The superlattice period is found to scale linearly with the step spacing deduced from the substrate misorientation. The superlattice was found to be eliminated for heavy (10^{18} cm^{-3}) Si doping. This was interpreted in terms of impurity pinning effects at the advancing step edges.

The ability to grow these superlattice structures was interpreted in terms of a simple surface model, assuming the surface is completely unreconstructed. This is an extremely controversial point of view. In private conversations, the NTT people point out that if the surface were covered with H radicals, the dangling bonds would be satisfied, thus removing the driving force for reconstruction. Personally, I doubt very much that the surface is covered with H. Nevertheless, this would account for the orthogonal directions of step motion needed in MBE and OMVPE to achieve step-flow growth.

The vertical superlattice was found to have measurable effects on optical properties. Both optical absorption and photoluminescence spectra were found to be polarization dependent. This may mean that such structures will be useful for optical and electron wave interference devices.

N. Kobayashi, Y. Yamauchi, and Y. Horikoshi, NTT Basic Research Laboratories. Kobayashi gave an invited talk at ASPE on new surface spectroscopy measurements (surface photo absorption or SPA) made during OMVPE, or to be more precise ALE (atomic layer epitaxy), since the group III and group V precursors were supplied to the surface at different times. The basic idea is that at the Brewster angle (70°-80° from the normal) for light polarized perpendicular to the surface (p-polarization), the absorption due to the bulk epitaxial layer is a minimum. Under these condition the electromagnetic (EM) radiation can couple to the As-Ga bonds on the surface for one substrate orientation. This interaction is less when the polarization vector is rotated by 90°. The difference in reflectivity is then used to derive chemical information about processes occurring on the surface. In addition, the photon energy can be scanned to obtain additional information about the bonds being probed. When the beam is incident along the [-110] direction, a peak is seen at about 2.5 eV. This peak disappears when the substrate is rotated by 90°. Thus, the peak is believed to be due to absorption due to the As-Ga bond at the surface.

The experiments are done in fairly simple OMVPE reactors that I saw when I visited NTT (see the later section describing this visit). Two reactors, one horizontal and the other vertical, have been equipped with the optical characterization apparatus. The windows must be purged with hydrogen to avoid obscurance. The light source is a 150-W Xe lamp with monochromator, polarizer, and chopper. An Si avalanche photodiode (APD) detector is located on the other side of the reactor. A window at normal incidence in the horizontal reactor can be used to monitor scattered light, to detect the occurrence of surface roughness due to droplet formation, three-dimensional nucleation, etc.

Measurements for the alternate supply of TMGa and arsine at 560 °C show a p-polarized reflectivity change of 2% for a wavelength of 480 nm. The Ga surface has a higher reflectivity than the As surface. Again, examination of the wavelength dependence shows that the 2.5-eV peak occurs only for the Ga-rich surface. A systematic change in the energy of this peak occurs when In or Al are substituted for Ga. In fact, the peak energy scales linearly with the group III-As bond strength.

Since the technique gives a measure of the Ga atoms deposited on an As stabilized surface, it can be used to measure the heterogeneous rate of pyrolysis of Ga precursors on the GaAs surface. This gives a direct quantitative measure of one of the important processes for ALE. It is also an important tool for gaining additional information about the surface processes occurring at atmospheric pressure. Thus, it is a nearly unique and potentially very valuable tool. However, caution should be used in assuming these rates will be good for OMVPE, since the group III and group V precursors, and their fragments, can interact on the surface to assist the pyrolysis processes. Kobayashi studied the pyrolysis of both TMGa and TEGa. He was able to assess the reaction kinetics. He was also able to give clear information about the saturation process, whereby the pyrolysis of the group III precursor stops after monolayer coverage. He found the saturation process to be due to termination of the surface by methyl radicals in the case of TMGa. He also found that at higher temperatures where deposition continued after a single monolayer coverage, the scattered light intensity increased. He was also able to measure the rate of desorption of methyl radicals from the surface. The time constant at 470 °C is 100 seconds. He found the activation energy for this process to be 32 kcal/mol.

Kobayashi also reported on studies of the heterogeneous pyrolysis rates of various As precursors. The activation energies of arsine, tertiarybutylarsine (TBAs), and diethylarsine were nearly the same, ranging from 0.736 to 0.822 eV. The activation energies for trimethylarsine and triethylarsine were higher at 2.93 and 1.58 eV, respectively. He interprets these results in terms of steric effects. The molecules with one or more H ligands can adsorb strongly, giving dissociative adsorption. The molecules with all methyl or ethyl radical ligands are sterically hindered from having strong interactions with the surface; thus, the processes are not effectively catalyzed by the surface. Personally, I have a hard time accepting this literally, since it is the lone electron pair, which should be exposed in all of these molecules, that interacts most strongly with the surface. Also, the 2.93-eV activation energy for TMAs is much higher than the well-known activation energy for homolysis.

In summary, this appears to be an extremely worthwhile new technique for the sorely needed in-situ measurement of surfaces processes in atmospheric pressure (as well as reduced pressure) OMVPE. I expect to see a rapid increase in these types of studies, since the experimental apparatus required is not elaborate or expensive.

"The Role of Step Kinetics in MBE of Compound Semiconductors" (T. Nishinaga and T. Suzuki, University of Tokyo). Professor Nishinaga gave an invited talk on the role of surface steps in the MBE of compound semiconductors. He postulated that, even though MBE is a basically nonequilibrium process, the attachment of atoms at the step edges is nearly in equilibrium. Thus, he developed a simple (overly simple, according to some observers) model of the incorporation of atoms during MBE where a supersaturation exists for the adatoms on the step away from the edges and equilibrium is assumed at both the front and back edges of the step. In another talk it was convincingly argued that atoms see a barrier for transport over the front edge, so equilibrium would be unlikely there. When the misorientation is small, giving wide steps, and the flux is relatively large, the atoms cannot diffuse to the step edges rapidly enough to avoid a large supersaturation near the center of the steps. This leads to two-dimensional nucleation. This was treated basically by the traditional capillarity theory, which is obviously not entirely appropriate for this situation.

He then presented the results of experimental studies of the dependence of alloy composition, for InGaAs, AlGaAs, and AlInAs, on GaAs substrates with different misorientation angles and directions. He chose growth temperatures high enough to allow evaporation of at least one of the group III constituents from the surface. Obviously, if this were not the case, the solid composition would only reflect the relative fluxes of the various group III atoms to the surface. He found that for GaInAs the solid composition varied with the degree and angle of misorientation. Thus, growth is not an equilibrium process. However, for AlGaAs and AlInAs the alloy composition was independent of surface orientation.

"Dynamics and Kinetics of MBE Growth" (B.A. Joyce, Imperial College, London). Professor Joyce reviewed the results of his group using rather more sophisticated surface models. They use more appropriate statistical-mechanical nucleation models than does Nakanishi and do not assume equilibrium at the step edges. Comparing their experimental results on two-dimensional nucleation from reflectance high energy electron diffraction (RHEED) measurements during MBE at various incident flux levels, they are able to derive several critical quantities including the activation energy for surface diffusion (1.3 eV). They predict that type A steps (for a [110] misorientation) will be nearly flat, with few kinks. The type B steps (for [-110] misorientation) are extremely rough and type C (for [010] misorientation) are in-between. An important new point mentioned in Joyce's talk is the ability to see reflectivity difference (RD) oscillations during MBE growth, with both As and Ga beams continuously on. (RD oscillations are normally observed for the ALE mode of growth where the group III and group V beams are modulated out of phase.) The RD oscillations correspond directly to the RHEED oscillations. The morphology is not modulated during growth, so the oscillations must be due to changes in the chemistry, perhaps the surface stoichiometry, during growth. This result is extremely exciting for OMVPE people, since this technique offers the best possibility of in-situ monitoring of the process.

"Step-Density Dependence of Growth Rate on Vicinal Surface of MOCVD" (M. Kasu, H. Saito, and T. Fukui, NTT Basic Research Laboratories). The results of interesting studies of the dependence of GaAs growth rate on substrate misorientation were presented. The substrates were misoriented toward the [-110] direction by angles of from 1° to 4°. The growth rate was studied by the very sensitive technique of examining the superlattice period of $(AlAs)_{0.5}(GaAs)_{0.5}$ vertical superlattices using x-ray diffraction satellite peaks. They found that the growth rate increases by 2% as the misorientation increases from 1° to 2°. This is due to the increase in the step density. For wide steps, the group III precursors, or their intermediate products, may desorb from the surface before reaching a step edge where they are incorporated.

SUMMARY OF COMPANY VISITS

NTT Basic Research Laboratories, Musashino, Tokyo

Dr. Kobayashi and Dr. Horikoshi were my hosts for the day. Horikoshi described his recent progress in MBE and MEE, as described above, since he gave an invited talk on this subject at ICVGE-7. I found his work on extremely high mobility AlGaAs/GaAs structures most interesting, including the asymmetry in resistivity and the ballistic effects he observes for van der Pauw measurements on small samples. His ideas about surface reconstruction effects on epitaxial growth are directly relevant to current work on the formation of ordered structures in III/V alloys grown by both MBE and OMVPE. We have assumed that the surface reconstruction and step motion during OMVPE are similar to MBE, where a better idea of these processes can be obtained from in-situ experimental observations. The work of Horikoshi and Fukui on the occurrence of step-flow growth in the two techniques seems to bring such assumptions into question. They find that [-110] steps are rough but are necessary for the growth of horizontal superlattices in MBE and MEE. On the other hand, [110] steps are necessary for the growth of horizontal superlattices by OMVPE and are therefore thought to be rough. They interpret this difference to the passivation of all surface bonds by adsorbed H atoms in OMVPE. I have reservations about their interpretation of the experimental results in terms of specific surface structures.

By far the most interesting results for an OMVPE person, such as myself, were the beautiful surface spectroscopy results of Kobayashi and coworkers. This is discussed in detail above in relation to Kobayashi's invited talk at ASPE. The experimental apparatus is attractively simple, although more elaborate versions are currently being installed. This appears to be an extremely attractive and promising technique for the in-situ measurement of surface processes in OMVPE, although to date the technique has proven successful only for the alternating supply of group III and group V precursors, as for ALE growth.

I also had discussions with Mr. Nozawa, who described successful growth of GaAs on Si substrates using MEE at very low temperatures to avoid the thermal expansion mismatch responsible for many of the defects in GaAs on Si. MEE growth at 300 °C resulted in GaAs with dislocation densities as low as 10^4 cm^{-2}, a very impressive number. The catch is that any high temperature steps in either growth or processing cause the generation of dislocations. Thus, no laser devices have been fabricated in this material.

University of Tsukuba

My host at the University of Tsukuba was Professor Fumio Hasegawa, in the Institute of Materials Science. He is working on the difficult problem of growing AlGaAs epitaxially using the chloride VPE technique. He uses independent $AsCl_3$ sources for the transport of Ga and Al to the epitaxial layer. The $AsCl_3$ reacts with liquid Ga at 750 °C to form GaCl and with solid Al at 650 ° C to form $AlCl_3$. These are reacted with the As produced at 750 °C to form the AlGaAs layers with Al contents of from 15% to 54%. The layers are contaminated with Si since the $AlCl_3$ reacts vigorously with the hot silica walls, even though they are coated with carbon. He has also grown AlGaAs and GaAs using $GaCl_3$, $AlCl_3$, and arsine as sources at a substrate temperature of 600 °C. The group III trichlorides were contained in stainless steel containers at temperatures between 60 and 120 °C. GaAs can be grown using $GaCl_3$ and either AsH_3 or elemental As. Apparently $GaCl_3$ is able to react directly with arsine. His group is also studying the ALE growth of GaAs using $GaCl_3$ and arsine. This is an interesting approach to reducing the carbon contamination commonly observed in

ALE using organometallic group III precursors. This technique has been attempted for AlGaAs without success to date.

I also visited with Professor Kawabe, who is an MBE specialist. He is doing interesting work with the addition of atomic H during growth. This was originally used for the in-situ cleaning of Si surfaces for the low temperature growth of GaAs on Si. Low temperatures are necessary because most of the defects come from the thermal expansion coefficient mismatch between the two materials. The atomic hydrogen is produced from H_2 by a heated tungsten filament. He and his students have recently shown that the addition of H during MBE growth allows for selective growth on SiO_2 or SiN_x masked substrates at 550 °C. The H produces volatile Ga and As species that leave the dielectric surface while growth occurs on the GaAs surface. For normal MBE, growth temperatures in excess of 700 °C are necessary to allow the Ga to vaporize from the dielectric substrate.

NEC Fundamental Research Laboratories, Tsukuba

My visit was hosted by Dr. K. Kakimoto. He showed me interesting results on the bulk growth of GaAs with diameters of up to 4 inches with x-ray observation for diameter control. They also use magnetic fields (6 T using a conventional magnet) to suppress convection in the melt. They take a very systematic approach of measuring the viscosity, thermal conductivity, etc. of molten Si and apply large-scale numerical calculations to predict optimum growth geometries and conditions and to interpret their results.

I also visited with Mr. Usui, who discussed ALE of GaAs and GaInAs using TEGa and TMIn plus Hcl for in-situ formation of DEGaCl and DMInCl. These molecules are ideal sources for ALE since they decompose to the monochlorides, which give a wide temperature range where one monolayer per growth cycle is deposited. They have also used a new precursor molecule, DMInCl, directly for ALE. Two types of ALE apparatus are used. One is a multibarrel reactor where the substrate is shuttled back and forth between the two gas streams (one only group V and the other only group III). The other is a conventional OMVPE reactor where the gas streams are switched back and forth above the stationary substrate.

I met Dr. Ono, who runs an elaborate ultra-high vacuum (UHV) transmission electron microscope (TEM) connected with a UHV deposition chamber. They are interested in observing directly the atomic arrangement on the surface during MBE growth.

Finally, I spoke with scientists using supercomputers to calculate from first principles (molecular orbital calculations) simple (for now) chemical reaction mechanisms. Elaborate and beautiful graphics are used to visualize the molecules vibrating, rotating, and eventually splitting apart. So far they have not gotten to organometallic molecules, but it is easy to envision that in the near future we will be seeing movies of tertiarybutylarsine molecules during the decomposition process. Naturally, such graphical simulations are extremely time consuming. However, with ever increasing computer power I would expect this to be a common research area in the future.

As with other laboratories in Japan, the growth, measurement, and computing facilities were impressive.

Optoelectronics Technology Research Laboratory, Tsukuba

A very impressive new laboratory is the Optoelectronics Technology Research Laboratory (OTL), also in Tsukuba. My visit was hosted by an old friend, the laboratory director, Dr. Izuo Hayashi. He formerly headed the Optoelectronics Joint Research Laboratory (OJRL) in Kawasaki, a Ministry of International Trade and Industry (MITI) funded laboratory staffed with researchers from several Japanese companies. OJRL was planned to have a finite life from the beginning. This was perceived as a mistake by Hayashi; thus, this laboratory is permanent. They have 10 years of funding at a level of approximately $8M/yr: 70% of the funding comes from the government and 30% from 13 industrial companies, including NEC, Hitachi, Toshiba, Sumitomo, Matsushita, and Oki Electric. The emphasis of the laboratory is very well defined. The twin objectives are to understand the surface processes occurring during epitaxy and to control these and other processes, such as beam assisted processing, to obtain atomic control of patterns in three dimensions. The fundamental information gained is then passed on to the 13 partner companies via a series of 13 device research laboratories, one at each company. The facilities assembled for the study of surface processes and beam assisted processing are beautiful and impressive, although the laboratory seems a little understaffed at present. Nevertheless, an impressive stream of research results has already begun. The tools brought to bear on the problem of epitaxial growth include several scanning tunneling microscopes (STMs), a UHV TEM connected directly to an MBE machine, x-ray photoemission spectroscopy (XPS) and other surface analytical techniques, an MBE/MOMBE (metal organic molecular beam epitaxy) machine with scanning RHEED (for local growth rate analysis), and a growth chamber coupled to a mass spectrometer and a thermally programmed desorption (TPD) apparatus. This part of the laboratory was planned and coordinated by Y. Katayama.

An example of the initial results is the study of ALE by MOMBE using either TMGa or TEGa and arsine in the system with a scanning RHEED. It is found that the self-limiting process involves adsorption of undecomposed molecules of the group III precursors. The Ga layer can be more than a monolayer thick during the group III part of the cycle. However, the group III precursor molecules in excess of a monolayer desorb when the group III flux stops. The mechanism of MOMBE growth of GaAs using TMGa and arsine has also been explored. In the same apparatus they also studied surface diffusion processes by growing on (001) surfaces adjacent to (111)A and (111)B facets produced by chemical etching. The growth rate is higher in the vicinity of the former and lower for the latter. The exponential distribution of growth rate, measured using microprobe RHEED, is believed to give a direct measure of the Ga diffusion length. Interestingly, the diffusion length along the [-110] direction is about 10 times higher than in the [110] direction. Diffusion lengths of nearly 10 microns are observed at 550 °C along the [-110] direction.

In related mass spectrometric studies in a modulated beam apparatus, the pyrolysis of TMGa on SiO_2 and GaAs surfaces was studied. As expected, the surface has a large effect, with pyrolysis being more rapid on a GaAs surface. It begins at about 350 °C. For the first time, they also demonstrated that the pyrolysis rate is higher on an As-stabilized surface than on a Ga-stabilized surface. The addition of As_4 on the surface had no effect on the TMGa pyrolysis rate.

These observations are directly related to efforts to produce microstructures. Using MOMBE (TMGa + solid As) they were able to achieve selective epitaxy using a gallium oxide mask produced by electron-beam-induced chlorine etching (to be discussed below). At 350 °C, pyrolysis of TMGa on the GaAs surface begins but is not initiated on the oxide surface until 550 °C.

The masked pattern is formed by oxidizing the GaAs at room temperature under illumination from a halogen lamp. An electron beam (EB) can also be used. The oxide layer was directly patterned by EB irradiation under Cl_2 gas. This removes the oxide without damaging the underlying GaAs. Focussed ion beams have been used in the past for maskless pattern formation. However, the high energy ion beams damage the surface, resulting in reduced minority carrier lifetimes, etc. The OTL people found that an electron beam will do the job equally well when the surface is exposed to a Cl_2 ambient. The resulting surface is undamaged. This EB-induced etching also works for AlGaAs. This process is now carried out in an impressive UHV system with seve interconnected chambers: loading, ample exchange, preheating, MBE, surface treatment, etching, and surface analysis. As I recall, the line widths obtained today are as small as 100 nm, although they plan to decrease this to about 10 nm in the near future. They will use this technique for the fabrication of two- and three-dimensional nanostructures in III/V semiconductors.

OTL also has impressive microscopy facilities. A major effort there is a study of the reduction of dislocations in GaAs on Si by using very thin, buried GaInAs or Si layers in the GaAs. A major effort relates to a fundamental study of the types of dislocations removed by a strained layer.

Hitachi Central Research Laboratory

Dr. Minegawa hosted my visit to the Hitachi laboratories. I saw work in a number of areas, including the growth of ZnSSe for blue-green lasers, a hot topic around the world since the very recent announcement by the group at 3M of injection lasers operating slightly below room temperature in this system. Apparently several laboratories in Japan have serious efforts in this area and are "hot on the heels" of the 3M group.

I also saw novel work on the growth of GaAs whiskers by low temperature OMVPE (TMGa plus arsine). The mechanism is that the arsine pyrolysis is so slow at low temperatures (380-500 °C) that the surface becomes Ga-rich. This results in the vapor-liquid-solid (VLS) growth of whiskers. We and others have observed similar whiskers for OMVPE growth of GaAs, InAs, and InP when the V/III ratio is too low. The Hitachi group found that the whiskers prefer to propagate in the [111] direction; thus, they used (111)-oriented GaAs substrates so that the whiskers are normal to the surface. They control the location of the whiskers by using an SiO_2 mask with small holes opened in it. This results in whiskers as thin as 10 nm, barely small enough to produce a quantum size effect in these "quantum wires." Impressive transmis sion electron micrographs show that the whiskers are filled with stacking faults. Photoluminescence (4.2K) spectra were obtained from the whiskers. As expected, the peaks occur very near those of GaAs epitaxial layers.

Researchers at Hitachi have been studying ordering in GaInP for a number of years. The results I saw simply confirmed earlier impressions. They have obtained material that is mainly composed of ordered domains. These samples show very strong electron diffraction intensities in the superlattice spots. However, some of these materials do not show the reduction of bandgap normally (by other researchers in the field) associated with ordering. They doubt that ordering results in a decreased bandgap energy.

Kyoto University

Professor Sasaki was my host a Kyoto University. Overall, his laboratory is extremely well equipped for a Japanese University. They have several OMVPE and MBE machines as well as a laboratory for device fabrication. A big problem is that they have few Ph.D. students (three at Kyoto, as I recall). Much of the work is done by the three research assistants, a little like assistant professors in the United States, and undergraduate students. At dinner, his wife informed us that Sasaki works from 8 a.m. to midnight, 6 days a week, and a few hours on Sunday. Perhaps this is why his laboratory produces so much good work over such a broad range of topics from fundamental materials work to device studies. We discussed his work on alternate precursors to arsine and phosphine, an area of interest for me. His student reported on the use of a Pt-Al_2O_3 catalyst to produce atomic H from H_2 to reduce carbon in GaP grown using TMGa and TEP. His group also does theoretical and experimental studies of the atomic structure of III/V alloys, including ordering, clustering, etc.

The research interests of Professor G.B. Stringfellow center on new semiconductor materials, structures, and devices. The emphasis is on III/V semiconductors, with interests ranging from the thermodynamics of III/V alloys, epitaxial techniques used for their growth, and their electrical and optical properties, to the growth of superlattice structures. His group is well known for pioneering research on organometallic vapor phase epitaxy (OMVPE). This includes the search for new precursor molecules to replace the hazardous group V hydrides as well as fundamental studies of the thermodynamics and kinetics of OMVPE. The range of materials studied includes a series of immiscible alloys such as GaAsSb, InPSb, GaPSb, GaInAsSb, and GaInPSb. His group has also done leading research in the growth of high bandgap alloys, such as AlGaInP, for visible light emitting diodes and lasers, and small bandgap alloys, such as InAsSbBi, for photon detectors operating at wavelengths as long as 12 microns. Stringfellow received a Ph.D. degree in materials science from Stanford University in 1968. He then spent 13 years at Hewlett-Packard Laboratories in Palo Alto, California, before becoming a joint professor of Materials Science and Engineering and Electrical Engineering at the University of Utah in 1980. He has been a visitor at the Max Planck Institute in Stuttgart (1979) and was a Guest Fellow of the Royal Society at the University of Oxford in 1990. He received the von Humboldt U.S. Senior Scientist Prize in 1979 and the University of Utah Distinguished Research Award in 1989. He is a Fellow of the IEEE.

RESEARCH ON VLSI FOR DIGITAL VIDEO SYSTEMS IN JAPAN

This report reviews research on design and implementation of very large scale integration (VLSI) systems for digital video technology at Graphics Communication Technologies (GCT) [in collaboration with Bell Communications Research (Bellcore), NJ, U.S.], NTT, and NEC. First, GCT/Bellcore's complete dedicated integrated circuit approach to design of a video codec is reviewed. Then NTT and NEC's video signal processor approaches to high-definition television video signal processing are described.

by Keshab K. Parhi

INTRODUCTION

The availability of devices for data acquisition, data storage, and printing and display; advances in very large scale integration (VLSI) integrated circuit (IC) technology; and advances in image compression techniques have now led to the feasibility of high quality digital transmission of color video images (Ref 1-4). Representation of color video images requires a vast amount of data, and real-time transmission of such images can only be done if compression ratios by a factor of 50 or 100 can be achieved. Fortunately, the current video compression technology (Ref 5) can meet this demand. This observation implies that we will, in the near future, be able to use color fax, color scanners, low-cost video phones, video teleconferencing, transmission of color medical images and newspaper transmission, etc. These advances will also lead to high-definition television in private homes. But, all these things will become reality only if they can be provided at low cost. Research on VLSI implementation of systems for video phones, video teleconferencing, transmission of still and moving images, and high-definition television is now being pursued world wide.

Processing of vast amounts of data (as in a video frame) can be done in one of two ways. First, dedicated or application specific integrated circuits (ASICs) can be used. These circuits offer limited or no programming flexibility and perform the dedicated functions in a very efficient manner. As a result, these designs are silicon area efficient and consume less power. A second approach is to use a massively parallel processor based system. In this approach, tasks are allocated in such a way that the processors are kept always busy (in other words, the load among processors is always approximately balanced). This can be done in many ways. For example, different processors can perform identical portions of the algorithm on different parts (or blocks) of the video frame. Alternatively, different portions of the algorithm can be executed by different processors (on identical blocks of data of the video frame) in a pipelined (or skewed) manner. These parallel processors are referred to as *video signal processors* (VSPs). Video signal processors have the advantage of programmability; thus, different applications can be programmed on the same system. But rapid prototyping of different applications using video signal processors can only be achieved if very efficient compilers are available. Thus, research in compiler technology is necessary. The drawback of the VSP approach is that it can be more expensive and can consume more power.

GCT/Bellcore has a dedicated approach to design of a video codec (Ref 6-12). The GCT Corporation is 70% supported by the Japanese Government and 30% supported by private organizations. This collaborative research is carried out by

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In this dedicated approach, each portion of the image compression in the encoder/decoder is carried out by one integrated circuit. The complete codec requires 14 different chips and 11 different designs.

The project HiPIPE (highly Parallel Image Processing Engine) for super-high-definition (SHD) image processing at NTT is carried out by

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The HiPIPE consists of 128 processing elements connected in a mesh manner (Ref 13-14). The HiPIPE system has been shown to be twice faster than the Cray-2 for still image coding tasks.

Another VSP system has been designed at NEC, and this system is referred to as HD-VSP (which stands for high-definition video signal processor) (Ref 15). The HD-VSP consists of 8 clusters and 16 processors per cluster. This system can achieve a processing rate of 2.5 billion operations per second. This research at NEC is managed by

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This report is primarily based on talks presented at the 1991 IEEE International Symposium on Circuits and Systems held in Singapore from 11-14 June 1990. A brief overview of different image coding approaches and international image coder standards is presented. Then GCT/Bellcore's video codec design, NTT's HiPIPE, and NEC's HD-VSP systems are reviewed.

IMAGE COMPRESSION TECHNIQUES AND STANDARDS

In 1990, three international standards were completed. These are Joint Photographic Experts Group (JPEG) (Ref 2), Moving Pictures Experts Group (MPEG) (Ref 3), and H.261 (Ref 4). The JPEG standard is the first international standard for still, multilevel, digital image compression and was a result of joint collaboration between the International Telegraph and Telephone Consultative Committee (CCITT) and the International Organization for Standardization (ISO). The MPEG standard covers transmission of moving images and addresses transmission of video and associated audio and audio-visual synchronization. MPEG addresses video compression at 1.5 Mbits and audio compression at rates of 64, 128, and 192 Kbits/s. H.261 addresses the video codec standard for transmission of video services using the Integrated Services Digital Network (ISDN) channel. The video codec for the audio-visual services standard addresses transmission at px64 Kbits/s (where p can lie between 1 and 30).

The video compression techniques used in all these standards are not completely different. Furthermore, all these standards do not use a single compression approach; rather, all these standards use a combination of multiple independent compression techniques. This section briefly reviews different image coding techniques (for a detailed overview, see Ref 5). Compression can be *lossless* or *lossy*.

In *lossless* compression, the symbols can be recovered exactly (without any loss of information). An example of the lossless compression technique is Huffman coding. The Huffman code is a variable word length code. In this technique, code words that occur more frequently are assigned shorter code words and code words that occur infrequently are assigned longer code words.

Lossy compression does not guarantee exact recovery of the transmitted image. In other words, some information is lost. However, lossy compression preserves the visual quality of the image as observed by the human eye. Lossy compression can lead to compression by higher factors, whereas lossless compression leads to a small amount of compression.

Examples of lossy compression techniques include transform coding, predictive coding, subband coding, and vector quantization. We do not discuss vector quantization, since it is not used in any of the current standards.

Transform encoding/decoding can be viewed as a simple harmonic analyzer/synthesizer. In the transform coder (or encoder), each 8x8 block of image pels (or pixels) are decomposed into 64 spatial frequency components (these frequency components describe the frequency spectrum of the block of pels). Out of the 64 spatial frequencies, only the low frequencies contain most of the signal and these need to be transmitted (after being quantized); the higher frequencies do not contain any signal information and need not be transmitted. The transform decoder reconstructs the block of pels from the transmitted low-frequency signal power information. Although many possible basis functions lead to many transforms, the discrete cosine transform (DCT) is the most popular one and is always used for video compression.

Predictive coding transmits the difference of the pel and the predicted value of the pel (based on previous pels). This difference is quantized and transmitted.

In *subband* coding, the image is divided into several frequency bands. This is related to the DCT coding and, similar to DCT coding, the low frequency bands contain most of the signal energy. In subband coding, different bands can be quantized with different signal-to-noise ratios and different resources (i.e., with different numbers of bits). Some bands need not be transmitted at all.

In the case of moving images, *motion compensation* becomes an important issue. In the motion compensation technique, a block of pels is compared with a neighboring block of pels from the previous frame. If a match is found (to a certain accuracy using some criterion), then only the motion vector is transmitted (as opposed to transmitting the entire block of pels).

The JPEG standard for still picture transmission makes use of the DCT transform coder followed by a quantizer, followed by an entropy coder. The transform coded quantized data are entropy coded to further reduce the compression factor. The MPEG standard is similar to the JPEG standard, with the only difference being that motion compensation is used and motion vectors are transmitted in the case of a match. MPEG requires a bit rate of about 1.5 Mbits/s.

The video codec standard H.261 makes use of complex image compression techniques to achieve the desired compression. It makes use of predictive coding, transform coding, motion compensation, and Huffman variable word length coding. These compression techniques combined can lead to a compression ratio of 100. The primary application of H.261 is video teleconferencing using the ISDN transmission channels. To get an idea of the compression ratio needed for a H.261 video teleconferencing system, let us calculate the bit rate required for a video codec with 6 channels (i.e., it uses 6x64 Kbits/s channels). For this video codec, the luminance is represented by 288x360 pels and the two chrominance components are represented by 144x180 pels. Assuming a representation of 8 bits/pel, and 30 frames/s, the total bit rate of the uncompressed data is 37 Mbits/s. To send these data with 6x64 Kbits/s channels, we need a compression ratio of 100.

Beyond these three standards, video compression standards for higher resolution signals are currently under study. For example, the CCIR 601 higher resolution video standard requires an uncompressed data rate of 10 Mbits/s (486 lines, 720 pels/line, 30 frames/s), enhanced-definition TV (EDTV) requires a data rate of 15 Mbits/s (486 lines, 960 pels/line, 30 frames/s), and high-definition TV (HDTV) requires a data rate of 40 Mbits/s (1,080 lines, 1,920 pels/line, 30 frames/s). The standards for transmission of these higher resolution signals will be studied in the future.

GCT/BELLCORE VIDEO CODEC

The GCT/Bellcore implementation of the H.261 codec is a fully dedicated implementation. The total computing power required for H.261 encoders and decoders is 1.35 and 0.5 billion operations/s, respectively, assuming a frame rate of 15 frames/s (Ref 6). Liou and Fujiwara argue that this computing power can be met by fully dedicated implementations. They argue that the dedicated integrated circuit approach reduces the size of the codec from multiple shelves to multiple boards.

The video codec system consists of a total of 14 integrated circuit chips and 11 different designs. The different designs include

- prefilter and picture format processor chip (removes flicker noise, contains 15K gates in a gate array implementation)
- encoding system manager (contains 294K transistors) (Ref 7)
- DCT/IDCT chip (uses distributed arithmetic, contains 156K transistors) (Ref 8)
- motion vector detection chip (performs full block matching, contains 32K transistors) (Ref 9)
- buffer control and quantization (contains 83K transistors)
- variable word length encoder (contains 58K transistors) (Ref 10)
- forward error correction chip (contains 28K gates in a gate array implementation)
- variable word length decoder (contains 40K transistors) (Ref 11)
- decoding system manager (contains 60K transistors) (Ref 12)
- post filter (removes blocking effect, contains 10K gates in a gate array design)
- picture format converter (converts to NTSC format, contains 20K gates in a gate array implementation)

While the GCT/Bellcore approach has demonstrated the efficiency of a dedicated codec, it still needs to be further optimized for cost effectiveness. More aggressive designs can reduce the number of chips further. Of course, like all other systems, the cost will initially be high and will drop as the sale volume increases.

NTT HiPIPE ARCHITECTURE

NTT started the NOVI-I project in 1987 to study parallel signal processing methodologies (Ref 14). The HiPIPE system described in Reference 13 is the basis of the NOVI-II system. The HiPIPE architecture addresses image coding and transmission for super-high-definition (SHD) images, which have resolution superior to high-definition TV. NTT assumes these SHD images contain more than 2,048 lines and more than 2,048 pels per line. They also assume each color to be represented by 24 bits (as opposed to 8 bits in standard HDTV). Obviously, this aggressive target image aims for future imaging systems; perhaps these will be a reality 10 years from now!

In the last 10 years, the programmable digital signal processor (DSP) technology has improved dramatically. The achievable computing power has increased fivefold, from 10 million operations per second to 50. This speed increase can handle the demands of many speech applications but not for image. Video signal processors need computing power of the order of 10 to 50 billion operations per second. NTT assumes that such high computational demand will be met by video signal processors containing many programmable digital signal processors.

NTT's multiprocessor system consists of 128 processors connected in a mesh manner. Each processor in HiPIPE uses a Transputer T800 communication processor. The peak performance of a T800 is 2.8 million floating point operations per second (MFLOPS), and the peak power of HiPIPE is 358 MFLOPS. The addition of a pipelined vector processor with a power of 100 MFLOPS (to each processing element) increased the peak performance to 12.8 GFLOPS. This computing power is adequate to meet the demands of SHD image processing. Fujii points out that a programmable development assist system eases the task of program development.

Fujii used the HiPIPE system to evaluate the performance of still image coding and low bit rate motion picture coding. These image coding tasks contain a set of regular operations (identical for all blocks) and some irregular operations. The irregular operations demand more efficient load balancing. NTT uses two-dimensional butterfly data shuffling to balance the load when irregular operations are executed (Ref 13). The final result is that (with data shuffling) the NOVI-II system (based on HiPIPE) is twice as fast as the Cray-2. But one should note that the operations in Cray-2 are double precision operations, whereas the operations in NOVI-II are single precision operations. Therefore, the comparison is not exactly a valid one!

The longer term objective of NTT is to develop new algorithms for SHD moving image coding. I assume NTT plans to use this high performance engine to quickly develop new algorithms. If NTT can propose a new algorithm for SHD moving image coding, they will perhaps be the first to propose such techniques at a time when others may be addressing HDTV coding. Even then the programming of the NOVI-II system needs to be made easier with advanced compilers. These advanced compilers should automatically be able to carry out load balancing and should accommodate efficient memory management. Although the NOVI-II will be a very useful system to develop new image coding algorithms and in defining standards, the final standard, I believe, will need to be implemented by dedicated circuits.

NEC's HD-VSP SYSTEM

NEC proposes an HD-VSP video signal processor for real-time implementation of HDTV image transmission systems (Ref 15). NEC's HD-VSP consists of eight VSP clusters and programmable time expansion/compression units, and each cluster contains 16 processing elements. The total computing power is 2.5 billion operations per second.

The HD-VSP achieves its computational power from two programming methodologies, the overlap-save and overlap-add. In overlap-save, each processor makes use of data for the subregion which it needs to process as well as data from some neighboring subregions (this eliminates any communication requirement). In the overlap-add methodology, the subimages produced by individual processors are expanded across their subregions to overlap with neighboring subimages.

Each video signal processor can perform 11 million instructions/s. In each instruction cycle, the VSP can perform a multiply-add calculation or a block matching operation (for motion vector estimation for motion compensation). The computing power of each VSP is 20 million operations/s (since each cycle can perform two to three operations); therefore, the total power of a 128 video signal processor based HD-VSP is 2.5 billion operations/s.

While HDTV coding can be achieved with the HD-VSP, a dedicated implementation would be more efficient in terms of space and power (each VSP in HD-VSP consumes 12 watts!). But a dedicated implementation cannot start until a standard has been defined. A standard can only be defined after the algorithm design phase is complete. The algorithm development phase will be eased using the HD-VSP.

Efficient compiler design for the HD-VSP is another important task. In his context, Nishitani's group at NEC has already done some useful work in compiling signal processing algorithms for programmable DSPs (Ref 16). But extending these ideas to HD-VSP is not a trivial task and needs to be addressed.

CONCLUSION

The dedicated integrated circuit approach by GCT/Bellcore was feasible only because the standard for video codec had become available. This implementation (after some more design improvements) will become cost effective. This video codec will be the basis of video phones and video conferencing applications (using ISDN channels).

On the other hand, HiPIPE and HD-VSP are both very useful systems in terms of program and system development for defining algorithms and standards for HDTV and super HDTV moving picture transmission. Without such aggressive programmable systems, the algorithm design and standardization phase would take years! After HDTV and super HDTV standards are available, dedicated circuits will again make VLSI implementations cost effective; these circuits will require less silicon area and will consume less power.

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